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THE EFFECTS OF DIFFERENT WATER-REGIMES ON THE GROWTH OF PLANTS UNDER GLASS

II. EXPERIMENTS WITH LETTUCES (*LACTUCA SATIVA* LINN.)

By A. M. MAJMUDAR* and J. P. HUDSON
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In a previous paper Salter (1954) reported striking effects when tomato plants grown under glass were subjected to different water-regimes from the time the plants were well established to the end of the season, a period of about five months. Richards and Wadleigh (1952) have reviewed the effects of soil water on plant growth and compiled a bibliography of earlier work in which attempts were made to grow plants under controlled soil moisture conditions, but there is still a lack of precise information on methods of maintaining strictly definable and reproducible water-regimes and on their use in studying the water requirements of crop plants.

The principal feature of the water-regime technique is to set plants in soil of known moisture status and then to allow the soil to dry to a predetermined condition, after which it is re-wetted to field capacity but without any leaching of surplus water. Repetition of such cycles of controlled wetting and drying constitutes a definable and reproducible water-regime, the effectiveness of which depends on the accuracy that can be achieved. Hudson, Salter and Majmudar (1957) and Hudson (in press) have discussed methods of controlling water-regimes in experimental work and described the steps which are necessary for their effective use.

The results of Salter's work suggested that similar experiments should be carried out on other crop plants and led to the present work on lettuces which has shown that species may vary considerably in their reaction to different water-regimes at different stages of growth. The opportunity was also taken to develop the experimental technique so that it could be used in the study of crops growing out of doors in the dry seasons of a monsoon climate, using the methods of growth analysis (Gregory, 1926) for the study of the effects of various treatments.

Experimental methods.

The plots.

Excavations were made in the floor of a glasshouse and cemented brick walls about 90 cm. high were built to enclose twenty plots, each 135 × 70 cm. (Fig. 1). The whole group of plots was surrounded by a path to guard against the acute edge effects which occur close to the outside walls of a glasshouse. The plots were filled with 75 cm. of soil replaced in the natural order of horizons, the profile consisting of about 45 cm. of coarse sandy loam top-soil overlying about 30 cm. of well-drained cultivated subsoil, which in turn rested on structured, but undisturbed, Keuper marl.

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Four lysimeters were also constructed of the same size as the twenty plots but provided with water-proof concrete bases from which drains ran into a deep trench, where excess (gravity) water could be caught and measured. The twenty plots with natural drainage and the four lysimeters enabled four treatments to be replicated six times in randomized blocks, one block consisting of the lysimeters.

Plant material.

In experiments from autumn to spring the lettuce variety Cheshunt 5b was used, but for summer work Continuity, a variety usually grown out of doors, proved more suitable (see Varietal Trial below). In all experiments plants were raised under glass at moderate temperatures by sowing seeds in boxes of John Innes seed compost and pricking off into J.I. potting compost no. 2 in 3-inch clay pots, where they were grown to the 4- or 5-leaf stage. Plants were selected for uniformity before being set out in the plots at a distance (except where otherwise stated) of about 22 × 18 cm. This spacing gave 24 plants per plot in 4 rows of 6 plants.

Irrigation control.

Commercial "Grower's Model" soil moisture tensiometers were used throughout for measurement of moisture tension and proved most suitable and reliable for this work. The methods of irrigation control were essentially similar to those in Salter's work. Tensiometers for control of watering were installed mid-way between two plants in four key plots selected at random, one from each treatment, with the centres of the tensiometer pots at a depth of approximately 7 cm., since preliminary observations had shown that the maximum concentration of lettuce roots occurred at about that depth. Additional tensiometers were installed at other depths.

It was expected that the highest tensions would be recorded by those tensiometers which had their pots in the zone of maximum rooting and tensiometers at other depths did, in fact, confirm that the zone of maximum rooting was also the zone which dried out most rapidly. When a key tensiometer showed the predetermined tension for that particular water-regime, all six plots receiving the treatment were irrigated with an amount of water calculated to re-wet the whole bed to field capacity and no more.

In earlier experiments the volume of soil to be re-wetted to field capacity was assessed by excavating sample plants to see how far the roots extended, but in later experiments, when more tensiometers were available, tensions were recorded at successive depths and the moisture deficit of each zone of the horizon was calculated separately from the known density of the soil and the moisture characteristic curve (Fig. 2), which was ascertained by the methods of Rogers (1935) and Stoeckeler and Aamodt (1940). The calculated deficits for each zone were then summated, an additional small allowance made for re-wetting the surface tilth in cases where this had dried substantially, and the total calculated water requirement was then applied to each plot receiving the treatment. This procedure proved to be both convenient and reliable, its reliability being checked after each watering by the readings of deep tensiometers, which showed whether the whole rooting zone had been re-wetted to field capacity, and by the behaviour of the lysimeter drain, which indicated whether any appreciable leaching had occurred. The application of these checks showed that moisture deficits were calculated with sufficient precision for the purposes of the

PLATE I

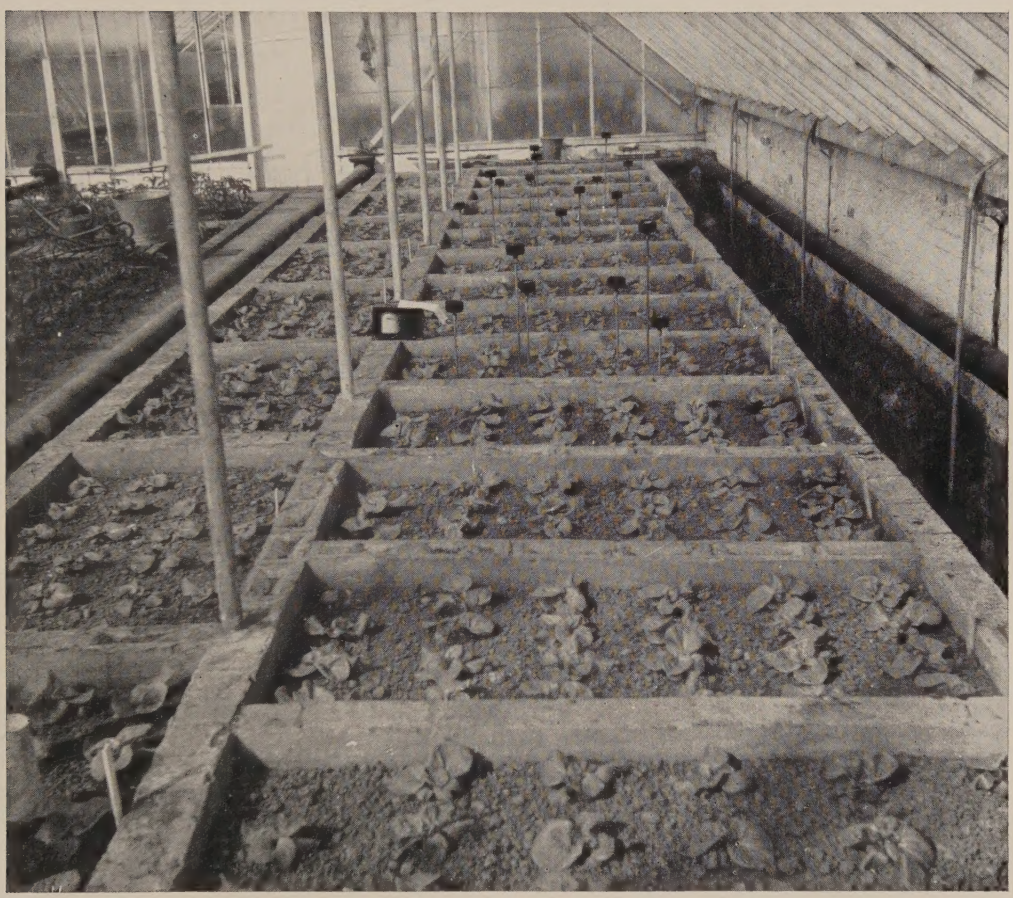

Fig. 1.

Layout of plots in the glasshouse. Note the black vacuum gauges of tensiometers.

[*face p. 202.*

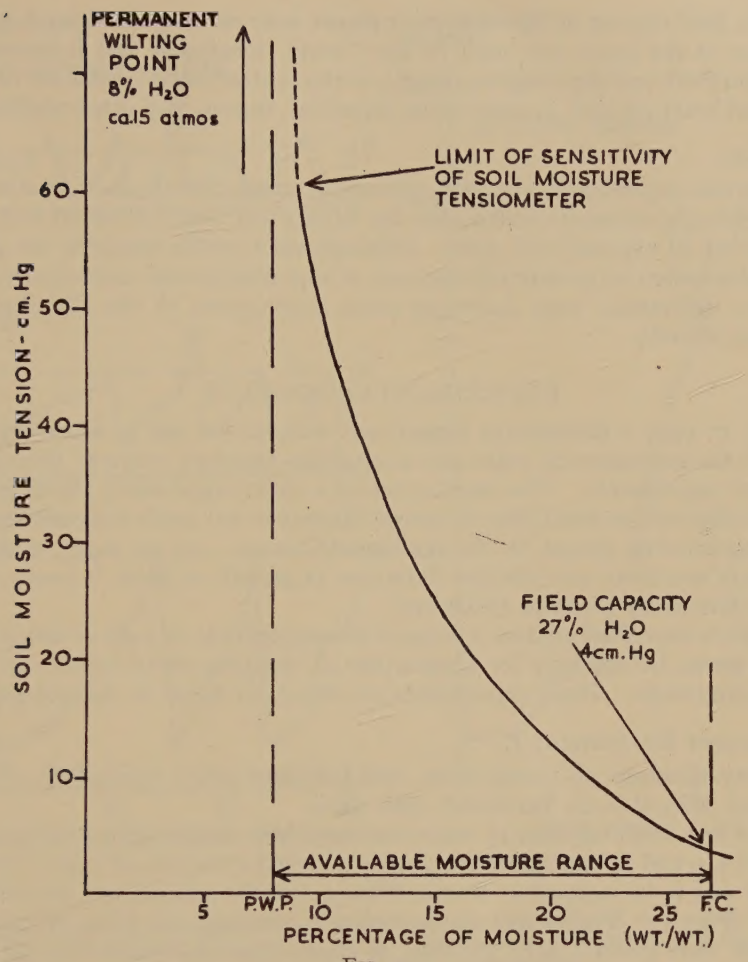

FIG. 2.

Moisture characteristic curve for the Sutton Bonington coarse sandy loam soil, showing the high proportion of available moisture which lies within the range of relatively low tensions.

present work, and that each irrigation re-wetted the whole block of soil to field capacity, but with negligible loss to drainage. In some experiments a small measured excess of water was applied when irrigating the lysimeters and the volume of effluent measured to give a further check on the calculations of water deficits.

Growth assessment.

Of the 24 plants in each plot (in all but the Spacing Experiment), data were recorded from the eight innermost plants at maturity, the outer lettuces being regarded as guard plants. For weekly observations on the progress of growth, plants were removed successively from corners of each bed and fresh and dry weights recorded, and in some cases further observational plants were removed from the guard rows but not early enough to affect growth of the innermost plants.

In the final harvest all the innermost plants were cut to ground level on the day when most of the heads felt solid in the "best" treatment and information was obtained on fresh and dry weights, lengths of the central stalks, incidence of tip-burn disease and heart rot and, in some cases, on colour, flavour and other attributes.

Root studies.

In several experiments one plot, selected at random from each treatment, was opened vertically across its width after the plants had been harvested and a profile map made of all exposed root ends. Although such profile mapping can give only limited information on quantitative aspects of root distribution, nevertheless striking qualitative differences were shown in some experiments in the distribution and orientation of roots.

EXPERIMENTAL RESULTS.

Early in 1954 a preliminary experiment was carried out to ascertain the uniformity of the experimental plots and to establish standard cultural procedures for subsequent experiments. The results showed a slight trend along the length of the house, but this was so small that no special allowance was made for positional effects in later experiments except by the randomized layout. At no stage in any of the experiments was there any obvious difference in growth or habit between plants in different plots under the same treatment.

The plots were then used for a series of six experiments, in each of which a lettuce crop was grown to maturity for the purpose of studying one or other aspect of its water requirements. These experiments are described below in chronological order.

Water-regime Experiment I.

Variety, Cheshunt 5b ; seeds sown, 25th February 1954 ; pricked off, 4th March ; planted out, 26th March ; harvested, 28th April.

In the first main experiment water was applied in three of the treatments when tensions of 5, 9 and 20 cm. respectively were recorded at depths of 7 cm. The fourth treatment was to be watered at 60 cm. tension, but the soil did not dry out to that condition (Fig. 3). Forty-eight hours before harvesting, all plots, irrespective of treatments, were given a light watering to ensure that the heads were fully turgid when cut and weighed. It was considered that this late damping down would not affect growth, but might prevent differences in turgidity from affecting fresh weights.

Table I.

Water-regime Experiment I. Effects on winter-grown Cheshunt 5b lettuces.

Treatment	Irrigation data*			Average fresh weight per head† (gm.)
	Tension at which water was applied (cm. Hg)	Number of times water applied	Total amount of water applied (cm.)	
A (Wettest)	5	5	4·2	193·0
B	9	4	5·4	192·5
C	20	2	3·8	194·5
D (Driest)	60	0	—	197·3

* From planting to two days before harvesting, when all plots were lightly watered.

† Except in Table II, averages were of eight plants per plot × 6 replications = 48 plants per treatment.

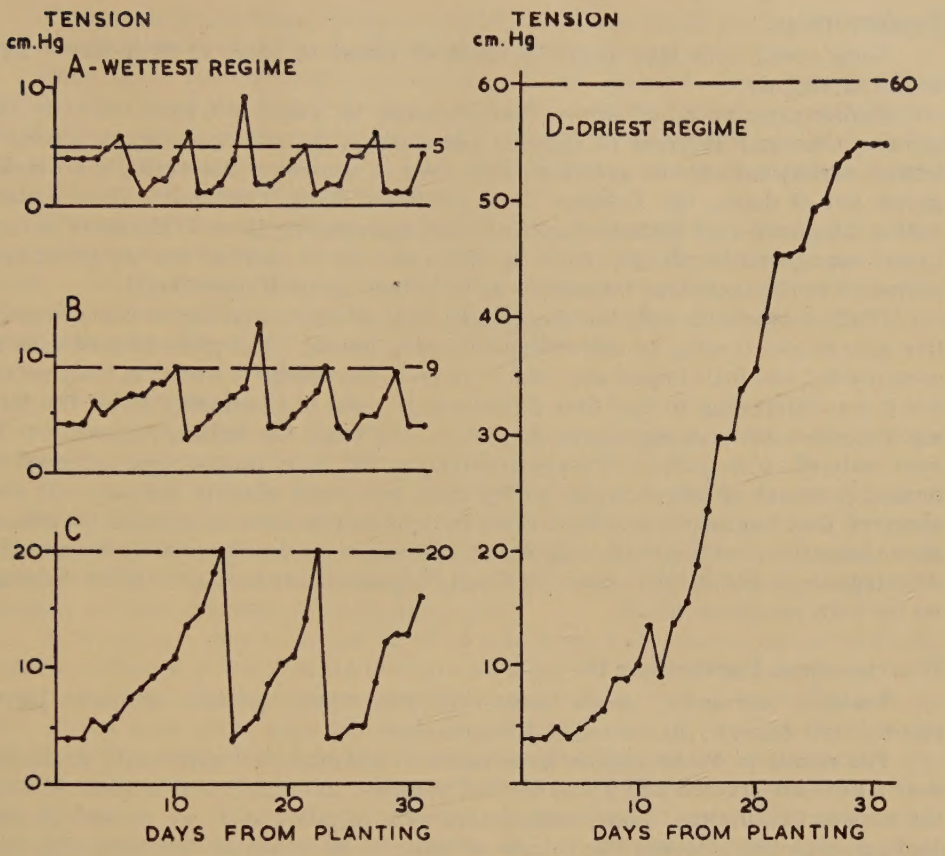

FIG. 3.

Curves showing soil moisture tensions, recorded daily at a depth of 7 cm. in the four treatments of Water-regime Experiment I and typical of other experiments. Sudden falls in tension in A, B and C were the result of irrigations.

Despite the wettest treatment being watered five times and the driest treatment not even once, there was no significant difference in the average fresh weights of the heads produced (Table I), nor did plants in different treatments show any observable differences in habit, size or colour at any stages in the growth of the crop (Majmudar, 1954). Winter (1955) has reported rather similar results from an experiment with Borough Wonder lettuces grown out of doors in a wet summer. Addition of irrigation water from the beginning of hearting to harvest time had no significant effect on growth or yield.

A study of root distribution showed that more roots had penetrated 60 cm. into the soil and that they were rather more uniformly distributed throughout the rooting zone, in the drier than in the wetter treatments; the volume of available soil, however, was not fully occupied by roots in any of the plots by the time the heads were ready to cut.

VARIETY TRIAL.

Seeds sown, 17th May 1954 ; pricked off direct to beds, 27-28th May ; harvested, 27th July.

Earlier experience had shown that Cheshunt 5b would not form hearts in the summer time and, in order to expedite the work, it became necessary to choose a lettuce variety suitable for growing under glass in summer. Six varieties normally grown out of doors, viz. Cobham Green, Feltham King, Continuity, Great Lakes, Sutton's Supreme and Sutton's Superb White, representing three of the main lettuce types, were therefore planted, three seedlings of each in each of the 24 plots, and subjected to the same four treatments as in Water-regime Experiment I.

Of the six varieties, only Continuity grew well, all others making excessive vegetative growth and tending to bolt without forming hearts. The plots became grossly overcrowded and little importance can be given to the results of watering treatments, but it was interesting to find that differences in yield of Continuity under the four water-regimes were not significant ($P = 0{\cdot}05$), although the beds in regimes A to D were watered 10, 7, 3 and 1 times respectively. The main purpose was achieved in finding a variety of lettuce which would grow well under glass in summer. It was observed that treatments had little effect on tendency to bolt, as assessed by rate of stem elongation, but there was a significant increase in the incidence of tip-burn in the drier regimes except in the varieties Feltham King and Great Lakes, the latter showing no tip-burn symptoms at all.

WATER-REGIME EXPERIMENT II.

Variety, Continuity ; seeds sown, 15th July 1954 ; pricked off, 24th July ; planted, 9th August ; harvested, 21st September.

The results of Water-regime Experiment I, although not apparently in doubt, were a little unexpected and it was decided to repeat the experiment in summer with the variety Continuity. Four tensiometers were installed at 7, 15, 30 and 45 cm. depth in each key plot and the volume of water to be added at each irrigation was assessed separately for each layer of soil from the moisture tensions and soil moisture characteristics (see p. 202).

TABLE II.

Water-regime Experiment II. Effects on summer-grown Continuity lettuces.

Treatment	Irrigation data*			Average fresh weight per head†	
	Tension at which water was applied (cm. Hg)	Number of times water applied	Total amount of water applied (cm.)	Without pre-harvest watering (gm.)	With pre-harvest watering (gm.)
A (Wettest)	5	12	7·6	187·1	218·3
B	9	6	7·2	209·8	206·9
C	20	4	6·2	224·0	218·3
D (Driest)	60	1	3·6	201·3	221·1

* From planting to two days before harvesting.

† Eight plants per plot × 3 replications = 24 plants per treatment. Treatment and sub-treatment differences not significant ($P = 0{\cdot}05$).

Three replications of each main treatment were given a light pre-harvest watering and three were not, to study possible effects of late waterings on yields.

Once again, the different water-regimes did not appear to affect growth (Table II), nor did the application of a light pre-harvest watering have any clear-cut effect on the fresh weight of lettuce heads. Sample plants in treatments A to D which had no pre-harvest watering had 94·7, 95·6, 95·6 and 95·0 per cent. moisture content respectively, and all appeared equally turgid.

Throughout the experiment plants under all treatments were strikingly similar in appearance and curves of growth rates showed no significant differences at any stage. No significant effects of the water-regimes were observed on either the rate of elongation of stems or the incidence of tip-burn but lettuces in the driest treatment were rather tougher in texture and had a bitter flavour.

Spacing experiment.

Variety, Cheshunt 5b ; seeds sown, 25th October 1954 ; pricked off, 3rd November ; planted, 2nd–3rd December ; harvested, 28th February 1955.

Since winter lettuces had not responded to irrigation under the conditions of earlier experiments it was assumed that a block of this soil, about 22 × 18 × 75 cm. in size and at field capacity, contained ample moisture for growth. It was, therefore, decided to ascertain the volume of wet soil necessary for producing marketable lettuces without irrigation after planting out.

As it was not easy to adjust depth of soil, crops were planted at four different spacings although it was realized that this arrangement might introduce the factor of aerial crowding. Four treatments were planted with 24, 32, 40 and 48 plants per plot, giving each plant approximately 394, 295, 236 and 197 sq. cm. respectively. All plots were wetted to field capacity before planting and no further water was applied during the experiment. Tensiometers were installed at six depths in each key plot and it was interesting to note that, despite the various number of plants in different treatments, soil moisture tension at any particular depth increased at similar rates in all the treatments. For instance, a tension of 60 cm. was recorded at 7 cm. depth in three of the treatments within 24 hours of each other. Soil moisture percentages, ascertained from samples taken on two dates, are given in Table III.

Table III.

Spacing Experiment. Effects on winter-grown Cheshunt 5b lettuces.

Plants per plot	Percentage moisture, wt./wt. basis, remaining at different depths as determined by drying soil samples (see Fig. 2 for equivalent tensions)					Effects on growth		
	After 16 days		After 89 days			Percentage of heads mature at harvest date	Average fresh weight per head (gm.)*	Total fresh weight per plot (gm.)
	7 cm.	15 cm.	7 cm.	15 cm.	30 cm.			
24	17·5	23·3	15·1	21·0	22·1	89	69·7	1,638
32	18·4	23·5	16·9	21·0	21·3	91	66·1	2,114
40	17·9	23·3	15·9	20·8	22·1	91	60·7	2,427
48	18·2	23·4	16·0	20·7	21·0	60	54·7	2,626

* Treatment differences highly significant (P = 0·001) : t test groupings, 24 & 32>40>48.

These results show that a cropping area under glass behaves in accordance with the general concept that potential transpiration is largely independent of number of plant population, provided plants form a complete cover and have access to freely available water (Penman, 1953).

In this experiment the effects of different treatments were highly significant although there was little observable difference in the appearance of plants. Heads matured at the same rates in three of the treatments but were retarded at the closest spacing. Both fresh and dry weights of individual heads were affected, increasing at wider spacing although the total fresh and dry weights per unit area of land were highest in the denser plantings. Similar effects of spacing have recently been shown by Nelder and Moss (1956).

Moisture Gradient Experiment I.

Variety, Cheshunt 5b; seeds sown, 22nd February 1955; pricked off, 2nd March; planted, 24th March; harvested, 28th April.

To overcome the effects of aerial crowding it was decided to compare treatments where plants were set out at the same spacings, but in soils containing different amounts of available water. Such treatments were feasible at this stage since the previous experiment had left all the plots dried out to a very similar degree (Table III). The amount of water required to re-wet each plot to field capacity was calculated and four treatments were given on the following basis :

E, sufficient water applied to re-wet the whole plot to field capacity.
F, with two thirds of the amount applied to E.
G, with one third of the amount applied to E.
H, no water applied except for a very small amount given direct to each plant at planting time.

Table IV.

Moisture Gradient Experiment I. Effects on winter-grown Cheshunt 5b lettuces.

Treatment	Changes in soil moisture tensions at various depths during the experiment								Average fresh weight per head* (gm.)	Average dry weight per head (gm.)
	Tensions on 24th March at time of planting (cm. Hg)				Tensions on 20th April (cm. Hg)					
	7 cm.	15 cm.	30 cm.	45 cm.	7 cm.	15 cm.	30 cm.	45 cm.		
E (Wettest)	3	4	4	1	60+	52	38	18	178·2	6·9
F	4	4	10	9	60+	54	52	25	159·8	6·6
G	4	15	12	9	60	57	46	37	136·7	5·8
H (Driest)	40	25	16	10	60+	54	43	36	131·0	5·4

Moisture tension in this soil at field capacity is about 4 cm. Hg. Tensiometers fail to record above a tension of about 60 cm. Hg and values shown as 60+ may have been considerably higher than 60 cm.

Treatment differences highly significant ($P = 0.001$) : t test groupings—fresh weights, E> F> G & H; dry weights, E & F>G & H.

* The considerable differences in size of head of Cheshunt 5b lettuces in the various experiments were due to seasonal variation.

Tensiometer readings after watering (Table IV) showed that the H plots were much drier than field capacity at all depths, although the soil became steadily moister at greater depths. The upper layers of plots F and G were at field capacity, to a greater depth in F than in G, with soils similar to H below. In E the whole plot was at field capacity, as in earlier experiments. No further water was applied to any plots during the experiment.

For the first time in this series of experiments it was possible to observe striking differences between plants growing under different treatments. Those in the wettest treatments grew better, had leaves of lighter colour and matured more rapidly. The last point is emphasized by the fact that nine days after cutting the experimental plants the proportion of guard plants running to seed in treatments E to H was 70, 58, 37 and 19 per cent. respectively.

Detailed studies were made of growth, since there is a great lack of precise data on growth of horticultural crops (Gregory, 1953) and growth curves (Fig. 4) clearly showed the depressing effect of moisture shortage from the second week after planting. Net assimilation rates were also worked out, following Watson (1952) but ignoring the dry weights of the root systems, which were shown in a subsidiary experiment to account for about 8 and 14 per cent. of the total dry matter under the wet and dry

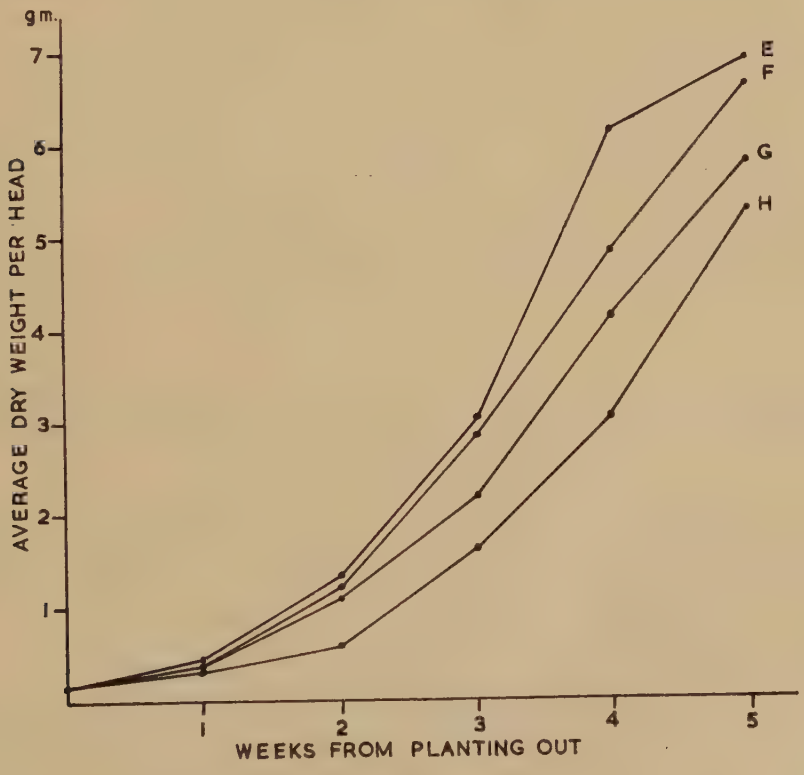

Fig. 4.

Growth curves of winter-grown Cheshunt 5b lettuces in Moisture Gradient Experiment I, based on weekly determinations of dry weights of aerial growth of six plants per treatment.

regimes respectively. Acute water shortage in treatment H appeared to depress net assimilation rate in the second week after planting out, but thereafter the rate was similar in all treatments.

Moisture Gradient Experiment II.

Variety, Continuity ; seeds sown, 17th May 1955 ; pricked off, 26th May ; planted, 14th June ; harvested, 19th July.

The previous experiment had left all plots more or less uniformly depleted of moisture and advantage was taken of this condition to carry out a final experiment in which treatments similar to D, E, F and G of former experiments were given to a summer-grown crop of Continuity lettuces. A study was made of the development of root systems under the different treatments. The new treatments were as follows :

D, plots re-wetted to field capacity before planting and watered when tension of 60 cm. Hg developed at depth of 7 cm. (cf. treatment D, p. 206).

K, plots re-wetted to field capacity before planting.

L, given two-thirds of the amount of water applied initially to D and K. This did not re-wet the lowest horizons.

M, given one-third of the amount of water applied initially to D and K, to re-wet a surface layer but leave an underlying dry zone.

No further water was given to treatments K, L and M after planting, but treatment D was watered once, on 1st July.

One week prior to harvesting one plot was selected at random from each treatment and the guard plants removed to facilitate identification of the fresh roots of experimental plants when these were subsequently excavated. Immediately after harvesting, excavations were made and the positions of all live roots mapped on the exposed profiles.

As in the previous experiment, treatment effects were reflected in the appearance of the plants, in their rates of growth and in fresh and dry weights of heads (Table V).

Table V.

Moisture Gradient Experiment II. Effects on summer-grown Continuity lettuces.

Treatment	Changes in soil moisture tensions at various depths during the experiment									Average fresh weight per head (gm.)	Average dry weight per head (gm.)
	Tensions at 15th June (cm. Hg)			Tensions at 1st July (D plots irrigated)			Tensions at 17th July (cm. Hg)				
	7 cm.	30 cm.	45 cm.	7 cm.	30 cm.	45 cm.	7 cm.	30 cm.	45 cm.		
D (Wettest)	5	4	5	60	17	7	60	58	57	239·3	8·2
K	5	5	4	60	22	7	60+	60+	60+	206·7	7·9
L	5	4	15	57	18	11	60+	60+	60+	178·6	7·2
M (Driest)	7	60	30	60	60	29	60+	60+	60+	88·0	5·4

Treatment differences highly significant (P = 0·001) : t test groupings—fresh weights, D>K>L>M ; dry weights, D,K & L>M.

The treatments also considerably affected the distribution of roots (Fig. 5). In treatment M, roots were virtually confined to the surface layer of soil which had been brought to field capacity by preliminary watering and few crossed the dry zone into the lower horizons of soil which contained more freely available water. In treatment L, roots crossed more freely through the narrower dry zone and there was a remarkable development of deep roots. Larger numbers of roots were observed in the driest treatments.

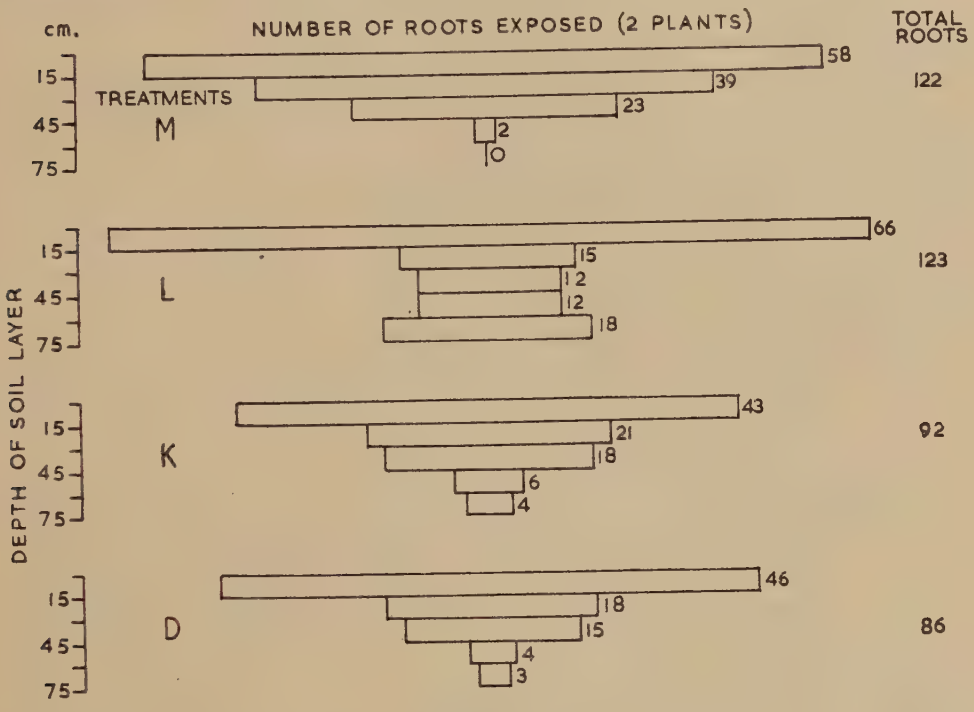

Fig. 5.

Effects of soil moisture conditions on the distribution of roots of summer-grown Continuity lettuces in Moisture Gradient Experiment II.

DISCUSSION AND CONCLUSIONS.

1. There are two methods of studying plant responses to soil moisture. One is to grow plants in soil of known moisture status, without further watering, and the other is to grow them in soil subjected to definable and reproducible water-regimes. Both methods were followed in this work, which has led to the following conclusions :

> The growth of lettuce plants does not appear to be increased by irrigation so long as roots are still growing strongly into moist soil. Such roots seem to be capable of supplying all the water which is needed under glasshouse conditions for sustaining rapid growth, even though the shallower roots remove moisture from the surface layers of soil to a tension of over 60 cm. mercury, a degree of dryness which approaches permanent wilting point in the soil used in the present experiment.

A block of coarse sandy loam soil at field capacity, 22 × 18 × 75 cm. in size (about 30,000 c.c.), can provide sufficient moisture for optimum growth of one Cheshunt 5b lettuce under glass in winter and the plant will not respond to further irrigation. Growth is, however, likely to be depressed by lack of water if the soil is drier than field capacity at planting time, or if the plant disposes of a lesser volume of soil at field capacity as a result of closer spacing. The same volume (about 30,000 c.c.) of soil at field capacity does not contain sufficient available water to sustain optimum growth of a Continuity lettuce under glass in summer and the plant will respond to irrigation.

2. In the management of irrigation it is necessary to know the latest stage in the drying cycle at which water should be applied to prevent shortage of moisture from affecting growth. The technique followed in the present experiments, based on the use of different water-regimes in separate plots and in lysimeters, should enable this stage to be ascertained with precision for any annual crop, provided rain can be prevented from falling on the plots during treatments.

3. The present work has shown that two phases can be clearly distinguished in the water relationships of lettuce plants :

Phase 1. Plants do not respond to irrigation if their roots are still extending into moist soil even though parts of the soil already occupied have been dried out to a considerable extent. In the first three experiments, plants were ready to harvest while still in this phase and thus gave no response to any of the watering treatments.

Phase 2. When all the moist parts of the rooting zone have been largely occupied by roots and the readily available moisture taken up, plants seem likely to respond to irrigation at quite moderate moisture tensions well within the available range. Plants reached this phase in one or more treatments in the last three experiments and thus showed treatment effects.

4. With glasshouse lettuces, Veihmeyer's hypothesis of equal availability of soil moisture from field capacity to near wilting point (Veihmeyer and Hendrickson, 1950) appears to be supported by experimental results in Phase 1, but not in Phase 2. In a concurrent paper, Salter (1957) draws similar conclusions for tomato plants grown under glass. There seems to be no unique moisture tension, as measured by tensiometers, at which growth falls off because of increasing moisture stress. The critical tension depends on the size and activity of the root system in relation to the depth and extent of the rooting zone and the availability of water in horizons still not occupied by roots. If experimental work is to point the way to the most efficient use of irrigation water, techniques must be sufficiently sensitive to show the relationships between all these various factors.

SUMMARY.

A technique is described for ascertaining the stage in the drying cycle at which water should be applied to a crop if growth is not to suffer from lack of moisture. This stage is not necessarily correlated with any particular value of moisture tension as measured by soil moisture tensiometers. In the early stages of establishment of an annual crop (e.g. lettuces) there may be no response to irrigation so long as roots

are growing strongly into fresh areas of moist soil, even though the surface layers have dried out almost to wilting point. At a later stage, when all the available rooting zone has been occupied or when roots are no longer growing strongly, plants may respond to irrigation at relatively low tensions. These relationships determine whether or not plants will respond to irrigation at any particular stage.

A bed of coarse sandy loam soil, 75 cm. deep and at field capacity, contains enough readily available water to produce a winter crop of Cheshunt 5 b lettuce under glass at normal spacings without further addition of water. The variety Continuity, grown under glass in summer, cannot obtain sufficient water for optimum growth from a similar volume of soil at field capacity but requires watering at least once if growth is not to suffer from lack of moisture.

REFERENCES.

Gregory, F. G. (1926). The effect of climatic conditions on the growth of barley. Ann. Bot., Lond., **40,** 1.

——— (1953). The control of growth and reproduction by external factors. Rep. 13th int. hort. Congr., 1952, **1,** 96.

Hudson, J. P., (in press). The study of plant responses to soil moisture, in Control of the Plant Environment, ed. *Hudson, J. P.* London : Butterworths Scientific Publications.

———, *Salter, P. J.*, and *Majmudar, A. M.* (1957). Water-regimes in irrigation research. Rep. 14th int. hort. Congr., 1955, 497.

Majmudar, A. M. (1954). Water relations of lettuces. Univ. Nottingham Dep. Hort. Res. Rep. 1954, 17.

Nelder, J. A., and *Moss, N.* (1956). The spacing of lettuce in heated glasshouses. J. hort. Sci., **31,** 177.

Penman, H. L. (1953). The physical basis of irrigation control. Rep. 13th int. hort. Congr., 1952, **2,** 913.

Richards, L. A., and *Wadleigh, C. H.* (1952). Soil water and plant growth, in Soil Physical Conditions and Plant Growth, ed. *Shaw, B. T.* New York : Academic Press Inc.

Rogers, W. S. (1935). A soil moisture meter depending on the capillary pull of the soil. J. agric. Sci., **25,** 326.

Salter, P. J. (1954). The effects of different water-regimes on the growth of plants under glass. I. J. hort. Sci., **29,** 258.

——— (1957). The effects of different water-regimes on the growth of plants under glass. III. Further experiments with tomatoes (*Lycopersicum esculentum* Mill.). J. hort. Sci., **32,** 214.

Stoeckeler, J. H., and *Aamodt, E.* (1940). Use of tensiometers in regulating watering in forest nurseries. Plant Physiol., **15,** 589.

Veihmeyer, F. J., and *Hendrickson, A. H.* (1950). Soil moisture in relation to plant growth. Ann. Rev. Plant Physiol., **1,** 285.

Watson, D. J. (1952). The physiological basis of variation in yield. Advances in Agron., **4,** 101.

Winter, E. J. (1955). Irrigation report. Nat. Veg. Res. Sta. Ann. Rep. 1954, 49.

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THE EFFECTS OF DIFFERENT WATER-REGIMES ON THE GROWTH OF PLANTS UNDER GLASS

III. FURTHER EXPERIMENTS WITH TOMATOES (*LYCOPERSICUM ESCULENTUM* MILL.)

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ALTHOUGH the tomato is the most important glasshouse crop in Britain, few experimental results have been published on the water relationships of this plant and authoritative guidance has been lacking on the irrigation of glasshouse tomatoes. Previous papers have described techniques used to study the effects of different, definable and reproducible water-regimes on growth and yield of tomatoes where plants were subjected to consistent regimes from fruiting to senescence (Salter, 1954a ; Hudson *et al.*, 1957). Subsequent experiments to determine the effects of alternating water-regimes at different developmental phases of the tomato plant are described in this paper.

The earlier work in the present series of experiments showed that both vegetative growth and yield of glasshouse tomatoes were adversely affected when irrigation of established plants was delayed until as little as 5 per cent. of the available water had been used and this was confirmed by other experiments on tomato plants grown in beds (Salter, 1954*b*). Rose and Dermott (1953), however, failed to obtain the same results with pot-grown plants under similar water-regimes. Kerr (1952) had earlier suggested that up to 30 per cent. of the available water might be allowed to be used up before the necessity of watering glasshouse tomatoes became urgent. In a recent paper, Gates (1955) described the effects of short periods of acute water shortage on the growth of young tomato plants and concluded that the changes occurring in response to moisture stress were initiated relatively early in the drying cycle. On the other hand, Went (1944), growing tomatoes in gravel cultures under carefully controlled environmental conditions, came to the conclusion that the water supply did not limit growth of the tomato plant except when moisture approached the permanent wilting point. Felföldy (1951) found that the different varieties may respond differently to soil moisture conditions whilst Morris *et al.* (1953) showed that the water uptake of glasshouse tomatoes grown at low soil moisture tensions was related to the total incoming solar radiation. The published work on glasshouse tomatoes thus still leaves room for considerable differences of opinion on the best way to irrigate this crop.

Many methods have been devised for watering glasshouse tomatoes in order to overcome the disadvantages of applying water by hose and especially its harmful effect on soil structure. Moen (1938) compared sub-irrigation with normal hose watering, but yields were smaller with the former system. The " ring culture " method described by Booer (1953) leads to the development of two different types of

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roots, namely, a massive system of water-absorbing roots in a porous medium which is watered daily so as to provide moisture at low tension, and a smaller root system growing in a container of soil which provides nutrients for the plant. High yields per plant have been reported for this method. " Trickle irrigation " is another system, which has been described by Searle (1954). Salter (1954*b*) compared it with other methods of applying water and found that trickle-irrigated plants gave higher yields than those watered by hose or can, even though water was applied when the moisture tension was about the same.

The responses of the tomato to various soil moisture treatments under field conditions have been described by many workers. With the varied conditions in different parts of the world it is not surprising that there is much variation in the results obtained. For example Lambeth (1954), working in Missouri, found that yields fell progressively when the crop was not irrigated until 25, 50 and 75 per cent. of the available water had been used up, whereas Schleusener *et al.* (1949) obtained their highest yields in experiments in Michigan by allowing 50 per cent. of the available water to be used before irrigating. Fröhlich (1955), after many years' work in Germany, suggested that optimum conditions for the tomato plant are provided when the soil moisture is kept above 70 per cent. of the water-holding capacity of the soil.

Few workers have examined the possibility that tomato plants may respond differently to variations in soil moisture at different phases of development, although such responses have been extensively studied in crops such as cereals, cotton and potatoes. In the commercial method of growing glasshouse tomatoes in this country, the first heavy watering after planting is traditionally withheld until the first, or alternatively the second, truss of flowers has set. Up to that time small quantities of water are usually applied to individual plants at fairly frequent intervals, a practice known as " ball-watering ", which defers the need for general watering of the whole bed and preserves the crumb structure at the soil surface for as long as possible. Bewley (1950) has claimed that growth can be readily controlled during this period of ball-watering by applying more or less water, and he was the first to suggest that heavy waterings should commence when the second truss of flowers had set (Bewley, 1928). The effect of lengthening or shortening the ball-watering period, or of omitting it altogether, seems not to have been fully investigated. Bacher (1940) has suggested, however, that tomato plants should be planted in damp soil and not be watered at all until the fruits begin to grow; small quantities of water should then be given until fruit picking starts after which watering should be liberal to increase both yield and size of fruits.

The object of the present experiments was to determine the effect, on subsequent growth, development and yield, of withholding water or supplying it to tomato plants during the early phase in their establishment after transplanting (the normal ball-watering period), and further, to ascertain the response of tomato plants to wet and dry conditions during subsequent phases of development.

Experimental methods.

The techniques used were essentially similar to those described in a previous paper (Salter, 1954*a*) and are only briefly mentioned here. Variations from these methods are noted under the accounts of the appropriate experiments.

The plots.

A glasshouse was subdivided into twenty-four plots, 210 cm. × 180 cm., by water-proofed brick walls which penetrated the subsoil. The plots were filled with soil comprising 20 cm. coarse sandy loam overlying 40 cm. of slightly heavier cultivated subsoil resting on well-structured Keuper marl. The layout of the plots enabled four treatments to be replicated six times in randomized blocks.

Instruments.

From past experience soil moisture tensiometers had proved satisfactory for measuring soil moisture at the relatively low tensions contemplated for these experiments. The tensiometer pots were buried at a depth of 15 cm. unless otherwise stated.

Cultural details.

Plants for all experiments, variety Ailsa Craig, were raised in $3\frac{1}{2}$ inch clay pots according to normal commercial practice. Before planting, the soil of all plots was brought to field capacity by flooding and draining, and differential watering treatments started on the planting date. Apart from watering, all plants received similar treatment throughout the season. The same total amount of nutrient was applied to all plots in soluble form in the irrigation water.

Irrigation control.

For the purposes of these experiments a water-regime was defined as a system of irrigation in which the soil moisture was allowed to range between field capacity and a predetermined level of dryness, as indicated by the moisture tension measured at 15 cm. below the surface (Hudson and Salter, 1953).

Unless otherwise stated, one plot, chosen at random, was used to control the watering of all the plots of that treatment, i.e., all plots were watered when the soil moisture tensiometer in this key plot indicated the predetermined tension. Readings were taken daily at 0900 hours to minimize the effect of diurnal fluctuations and the vacuum gauges were kept covered by cardboard cartons.

On each occasion when a plot was watered, sufficient water was applied to make good the calculated water deficit, thus re-wetting the whole of the soil approximately to field capacity. To provide a check for the calculation, deep tensiometers were used to show whether or not sufficient water had been applied to penetrate to a depth of 60 cm. whilst a series of four lysimeters, similar in shape and size to the experimental plots, was used to measure any excess of water which ran through to drainage.

Growth measurements.

Detailed measurements of growth and yields were made at frequent intervals on plants from each treatment. As a measure of the vegetative growth of the aerial part of the plants, the method of Ross (1946) was used in which the height of the plant is combined with its mean stem diameter by means of a regression equation (Salter, 1954*a*) to give a calculated dry weight.

Physiological phases in the growth of the tomato plant.

In these experiments the development of the tomato plant was divided into three phases, namely :

Phase I, from planting time until the first flowers set fruit (normal ball-watering period).
Phase II, from flower setting until the first fruits are picked.
Phase III, from the beginning of harvesting until the cessation of growth.

Leonard (1953) has shown that the beginning of fruit-set and the beginning of harvesting are turning points in the physiological activity of the tomato plant, and the subdivision into these phases seemed appropriate for the study of possible correlations between vegetative growth, fruiting and water supply. During Phase I growth is confined to the vegetative axis of the plant, although initiation and development of the earlier flower trusses also takes place. During Phase II vegetative growth is affected by fruit development (Murneek, 1926) and during Phase III the removal of fruit relieves some of the strain on the plant's resources.

EXPERIMENT 1953/1.

Seeds sown, 28th January 1953 ; planting out, 13th March ; ball-watering (Phase I), 13th March–20th April (39 days) ; water treatments (Phases II and III), 21st April–30th September ; first fruits picked, 25th May ; final recording, 30th September.

The main purpose of this experiment was to study the effects of four sustained water-regimes during Phases II and III on growth and yield, following the procedure of the previous year (Salter, 1954*a*). The various treatments and the results are set out in Table I.

TABLE I.

Irrigation particulars and mean yields per plant from 21st April to 30th September 1953 (inclusive).

Irrigation data					Average yield* per plant (kg.)	
Treatment designation	Method by which water applied	Tension at which water applied (cm. Hg)	Number of times water applied	Total amount of water applied (litres per plant)	Ripe fruit	Total yield (including green fruit)
T (wet)	Trickle	7	53	92·4	4·8	5·4
A (wet)	Watering can	7	88	98·7	4·2	4·7
B	Hose	15	11	108·3	3·6	3·9
C (dry)	Hose	30	9	105·1	3·4	3·6

* Based on sample of at least 50 plants.
Statistical significance : total yield per plant from treatment T or A significantly greater ($P < 0{\cdot}01$) than that of B or C ; difference in yield between treatments A and T barely significant at $P = 0{\cdot}05$.
S.E. per plot : 13·2 per cent. of the mean.

Table I confirmed the earlier findings that both growth and yield were reduced if, between irrigations, moisture tensions higher than a few cm. of mercury were allowed to develop in the plots after plants had reached Phase II. The results also showed that heavier yields were produced when the wettest regime was maintained by trickle irrigation than when water was applied over the whole soil surface.

Experiment 1954/1.

Seeds sown, 30th January 1954 ; planting out, 25th March ; ball-watering period (Phase I), 25th March–20th April (27 days) ; water treatments (Phases II and III), 21st April–30th September ; first fruits picked, 1st June ; final recording, 30th September.

In experiment 1954/1 traditional ball-watering and water-regimes involving heavier irrigations during Phase I were compared, to determine whether the subsequent yield of fruit was affected by the different soil moisture conditions at this period. Treatments during Phases II and III were the same as for experiment 1953/1. The tensions at which water was applied—namely, 7, 7, 15 and 30 cm. of mercury—indicated that approximately 5, 5, 35 and 50 per cent. respectively of the available soil moisture had been removed from the soil in the vicinity of the tensiometer pots. Thus it was possible to assess the effects of withholding general applications of water during Phase I.

Table II.

Average yields per plant, Experiment 1954/1.

Irrigation data			Average yield per plant (kg.)	
Main treatment	Method by which water applied	Tension at which water applied (cm. Hg)	Ball-watering followed by main treatment (48 plants)	Main treatment from time of planting (16 plants)
T	Trickle	7	4·0	3·0
A	Watering can	7	3·6	3·3
B	Hose	15	3·0	3·0
C	Hose	30	3·3	3·0

Table II gives the average yield of fruit per plant under the various treatments and shows the effect of commencing heavy watering from time of planting. The restricted layout of this experiment prevented a statistical analysis from being carried out but the indications were that heavy watering from planting time (during Phase I) reduced yields.

The main treatments, involving heavy applications of water, showed effects on yields similar to those found in the previous experiments. The low moisture tension regimes again gave the highest yields whilst trickle irrigation again gave slightly more crop than watering with the watering can at the same tension limits.

Experiment 1954/2.

Seeds sown, 6th June 1954 ; planting out, 17th July ; ball-watering (Phase I), 17th July–16th August (30 days).

In this experiment a comparison was made of the effects of different watering treatments on the growth of tomato plants during Phase I. Sixteen plants, selected for uniformity, were set out in each of six plots previously wetted to field capacity. Each plot contained a four-plant replication of four treatments to overcome differences in soil conditions which had resulted from previous irrigation treatments.

The treatments were as follows :

I, watered every day, 100 ml. per plant ;
II, watered at a mean tension of 10 cm. Hg,* 200 ml. per plant ;
III, watered at a mean tension of 20 cm. Hg,* 300 ml. per plant ;
IV, not watered at all during Phase I.

Each plant was watered individually and, at intervals of ten days, eight from each treatment were severed at their cotyledons, dried and weighed.

Table III.

Growth of plants in Experiment 1954/2.

Irrigation data			Average dry weight of shoots (gm.) (8 plants)			
Treatment	Control of watering	Total amount of water applied (litres per plant)	Days after planting			
			0	10	20	30
I	Each day	3·0	2·4	6·5	14·0	18·5
II	At 10 cm. Hg	3·3	2·4	5·9	12·3	18·7
III	At 20 cm. Hg	3·3	2·4	5·5	12·8	19·0
IV	Not watered	—	2·4	5·0	11·9	17·7

Differences in dry weights of shoots (Table III) were not significant, and the treatments had little observable differential effect on growth. The suggestion, therefore, is that plants make little response to the application of water during the first post-planting stage.

Experiment 1955/1.

Seeds sown, 7th January 1955 ; planting out, 14th March ; ball-watering (Phase I), 14th March–22nd April (40 days) ; main treatments (Phase II), 23rd April–27th May (35 days) ; main treatments (Phase III), 28th May–30th September (126 days) ; first fruits picked, 28th May ; final recording, 30th September.

The results of Experiments 1954/1 and 2 confirmed other workers' views that heavy waterings should be withheld for a time after planting tomatoes, but they also suggested that even the traditional ball-watering is unnecessary, provided that the soil is at field capacity at planting time. However, it was desirable also to study the effects of withholding water during Phase I on subsequent growth, development and yield of the same plants during Phases II and III. Moreover, the 1952 results (Salter, 1954*a*) had shown that plants developed different types of root systems under different treatments and it was therefore necessary to ascertain the effect of altering the water-regime part way through the season, after root systems of characteristic

* Mean readings of four tensiometers situated 7·5 cm. deep and 7·5 cm. from the bases of plants selected at random.

pattern had been produced. In the next experiment, therefore, plants were subjected to various water-regimes at different phases of growth to enable these points to be investigated. The plan of the experiment is set out in Table IV. The four main

TABLE IV.

Treatments in Experiment 1955/1.

Treatment	Ball-watering	Maximum permitted moisture tension (cm. Hg)	
	Phase I	Phase II	Phase III
AA	Ball-watered	7	7
	Not ball-watered		
CC	Ball-watered	30	30
	Not ball-watered		
CA	Ball-watered	30	7
	Not ball-watered		
AC	Ball-watered	7	30
	Not ball-watered		

treatments were replicated six times in a randomized block layout. Each plot was divided into two during Phase I, half the plants in each plot being ball-watered and the remainder not.

Growth measurements were made on six plants in each plot at weekly intervals during Phases I and II and at fortnightly intervals during Phase III. Because of the particular interest of the ball-watering treatments, twelve plants were removed for examination at intervals of a week from each of the two treatments during Phase I. From these plants, curves of dry weight increases were plotted for the two ball-watering treatments and an indication obtained of the effect of these treatments on percentage of dry matter produced by the end of Phase I. Yield of fruit was recorded separately for each of the experimental plants in all plots.

Effect of ball-watering on growth during Phase I.

The results are given in Table V. Growth was not significantly affected by the ball-watering treatments ($P>0{\cdot}05$).

TABLE V.

Growth during first 35 days after planting.

Treatment	Dry weight of shoots (gm.) (mean of 12 plants)			
	Days after planting			
	7	14	21	35
Ball-watered	2·8	5·4	10·4	38·2
Not ball-watered	2·6	5·4	10·2	36·8

One week after planting the percentages of dry matter in the sampled plants were 8·9 and 9·8 for the ball-watered and not ball-watered treatments respectively (a non-significant difference), whilst at the end of Phase I both were 7·7 per cent. Thus growth of tomato plants was again unaffected by withholding water during Phase I.

Effect of watering on growth made by end of Phase III.

Table VI gives the means of the calculated dry weights of the aerial parts of plants in the four main treatments and two ball-watering treatments. Ball-watering had no significant effect on the final amount of vegetative growth. On the other hand all main treatment means were significantly different from each other ($P < 0.05$) although differences between treatment means were not significant at the end of Phase II. The interaction between ball-watering and main treatments was non-significant.

TABLE VI.

Comparison of calculated dry weights (gm.) at the end of Phase III.

Treatment	Subsequent treatments (means of 18 plants)				Means
	AA	CC	AC	CA	
Ball-watered	195	179	157	166	174·2
Not ball-watered	197	182	154	171	176·0
Means	196·0	180·5	155·5	168·5	

Main treatments: S.E. per plot=10·6 per cent. of the mean.
Ball-watering treatments: S.E. per plot=9·6 per cent. of the mean.

Effect of watering on yield of ripe fruit.

Yields of ripe fruit for the main and ball-watering treatments are given in Table VII. The ball-watering treatment means, 3·31 and 3·62, were significantly

TABLE VII.

Effects of irrigation on yields from 23rd April to 30th September 1955 (Phases II and III).

Main treatment	Irrigation data				Yield of ripe fruit per plant (kg.) (means of 18 plants)		Main treatment means (kg.)
	Plant phase			Total amount of water applied (litres per plant)			
	I	II*	III*		Ball-watered	Not ball-watered	
AA	Ball-watered	7	7	215	3·71	—	3·79
	Not ball-watered	,,	,,	,,	—	3·86	
CC	Ball-watered	30	30	286	3·18	—	3·53
	Not ball-watered	,,	,,	,,	—	3·87	
CA	Ball-watered	30	7	148	3·09	—	3·39
	Not ball-watered	,,	,,	,,	—	3·68	
AC	Ball-watered	7	30	189	3·24	—	3·18
	Not ball-watered	,,	,,	,,	—	3·13	
Ball-watering treatment means (kg.)	Ball-watered				3·31		
	Not ball-watered					3·62	

* Maximum permitted moisture tension (cm. Hg) as measured by the tensiometers.
Main treatments : S.E. per plot = 11·6 per cent. of the mean.
Ball-watering treatments : S.E. per plot = 12·8 per cent. of the mean.

different ($P < 0.025$). Yields from the main treatment AA were significantly greater than from any other treatment whilst yields from CC were significantly heavier than from AC ($P < 0.05$). Higher yields were obtained from plants subjected to either of the sustained water-regimes (AA and CC) than from those subjected to soil moisture conditions which varied during different growth phases (CA and AC).

The effects of treatments on the size of fruits are shown in Table VIII. The sustained wet regime AA produced the largest fruit, the sustained " dry " regime CC slightly smaller fruit, whilst a larger proportion of small fruits was produced in the varied regimes CA and AC. The effect of ball-watering treatments on grade of fruit was not investigated.

TABLE VIII.

Percentage of different grades of fruit obtained from plants grown under various watering treatments.

Grade*	Treatments			
	AA per cent.	CC per cent.	CA per cent.	AC per cent.
Pink (5–8 to the lb.)	4·5	2·7	3·0	1·8
Pink and white (8–12 to the lb.) ..	49·1	47·2	42·0	36·5
White (11–16 to the lb.)	41·1	43·8	48·9	54·5
Chat (more than 16 to the lb.)	5·3	6·3	6·1	7·3

* As specified in the Ministry of Agriculture National " Recommended " Grade Scheme. The " Pink and white " grade is usually regarded as the most desirable in commercial practice.

DISCUSSION.

Responses in vegetative growth.

In previous experiments (Salter, 1954*a* and 1954*b*) a significant increase in vegetative growth was found for two varieties of tomatoes when the soil moisture tension was prevented from rising above 7 cm. Hg at any depth. A strikingly similar relationship between moisture tension and growth of sunflowers has been demonstrated by Frei (1955). Treatments AA and CC in the present work, comparable with A and C in the earlier experiments, again produced significant differences in vegetative growth (Table VI) although the differences were not of the same magnitude, while plants subjected to different regimes in Phases II and III made significantly less growth than those subjected to sustained moisture conditions throughout the period.

The response of tomato plants to soil moisture maintained high in the available water range is of particular importance, for it refutes Veihmeyer's hypothesis that soil moisture is equally available to plants at all points between field capacity and the permanent wilting point (Veihmeyer and Hendrickson, 1950). Veihmeyer and his co-workers have investigated the response of plants to soil moisture conditions near the permanent wilting point, but their experiments included very few treatments in which the soil moisture was maintained high in the available water range. This omission led them to assume from their results that soil moisture was equally available to plants over the whole range between field capacity and the permanent

wilting point, an assumption which many workers have proved to be untrue. It is interesting to note that if, in the earlier experiments on tomatoes (Salter 1954*a*, 1954*b*), the wettest regime selected had allowed 25 per cent. of the available water to be used in the driest rooting zone before re-watering, instead of only 5 per cent., then the results would have been in apparent agreement with Veihmeyer's hypothesis.

The stage of development of the tomato root system appears to determine the response of this plant to soil moisture. Under the conditions of this work, roots did not fully occupy the soil volume until after the fruit began to develop and only then did plants appear to respond to surface applications of water. For instance, in Experiment 1955/1 there were no significant differences in vegetative growth under the different treatments at the beginning of harvesting, indicating that up to that time plants had not been dependent on irrigation for a sufficient length of time for growth to be influenced. However, by the end of the experiment (Table VI), all differences in growth between treatments imposed after harvesting had begun were significant ; this implies a response to treatments during that phase, together with the possibility of some carry-over of responses during the previous phase which had not shown at the end of it.

Following this hypothesis further, it might be postulated that growth was affected by treatments applied only during Phase III and that differences in response to AA and CA treatments, or to CC and AC, should be non-significant since both received the same treatments in Phase III (see Table IV for key to treatments). This reasoning, however, does not take into account the effects which soil moisture conditions have been shown to have on the distribution of tomato root systems (Salter, 1954*a*). In wet regimes most of the roots developed in the surface few inches of soil in contrast to deeper development under drier regimes. Thus it is reasonable to postulate that a sustained water-regime, either wet or dry, provides better conditions for plant growth than varying regimes in which the type of root system developed under an early treatment is less well adapted to the conditions provided later. It can further be argued that the adverse effect on growth would be greatest when the change is from a wet to a dry regime since this must lead to many of the surface roots, formed under the wet regime, being subsequently subjected to severe moisture stresses. It is suggested that this hypothesis explains the experimental results.

When planted in soil at field capacity, tomato plants did not seem to respond to irrigation until their roots had fully occupied the available rooting zone, and it is interesting to find that Majmudar and Hudson (1957) have found a similar relationship for lettuce plants. Thus the relationship of the plant to soil water is influenced by depth of soil, the growth rate of roots and the moisture content at planting time.

Responses in yield of fruit.

The stage of development at which the plant was subjected to high or low soil moisture tensions had a pronounced effect on final yield. Excessive waterings applied to newly-planted tomatoes reduced the final yield of fruit, especially where low moisture tension conditions were maintained at a later stage (Table II). These results are in agreement with the recommendations of Bewley (1950) and Russell (1950) regarding the start of heavy waterings. Bewley, however, states that ball-watering must be carried on during this period to prevent the ball of soil from drying out, but the experimental results (Table VII) show that withholding water altogether

during this phase significantly *increased* final yields when plants were set out in soil at field capacity. Similar results were obtained by Bacher (1940). It should be noted that these findings may not be obtained when plants are set out into soil which is not at field capacity.

The results presented in Table II, when normal ball-watering was followed by the four experimental treatments, and in Table VII, are in agreement with those obtained in the earlier experiments, yields of ripe fruit being heaviest where a low moisture tension was maintained.

The relationship between soil moisture tension and yield is thus similar to that for vegetative growth. Relatively more vegetative growth tends to occur at low tensions even though there is also a significant increase in yield. Both Kerr (1952) and Lambeth (1954) have suggested that, to obtain high yields, tomatoes should be watered before 30 per cent. of the available water has been used.

Maximum yields were obtained from plants subjected to sustained water-regimes throughout Phases II and III, the wettest treatment (AA) producing a significantly higher yield of fruit than any other (Table VII). Treatment CC was a dry regime during Phases II and III ; nevertheless the yield was significantly greater than from treatment AC. There were also indications that the yield from treatment CC was higher than that from CA. These results can be explained by the hypothesis presented earlier, which relates root habit with responses to water-regimes. Vigorous vegetative growth is a prerequisite for high yields in the tomato and factors which affect vegetative growth are, therefore, also likely to affect yields.

The size of fruit produced is a matter of commercial importance. In all the experiments a larger average size of fruit was produced under the wettest regime.

SUMMARY.

Further experiments are described on the water relations of the tomato plant under glasshouse conditions. The period from planting to senescence was divided into three physiological phases, namely, from planting time until the first fruit began to develop, from commencement of fruiting until the first fruits ripened and were picked, and from this latter stage until senescence at the end of the season. The experiments were carried out to determine the optimum water-regime during each of these phases.

Results indicated that when tomatoes were planted in about twenty-five inches of sandy loam soil at field capacity, further applications of water to the plants before fruiting reduced final yield of fruit. After fruiting had started, maximum growth and yield was obtained from plants growing in soil maintained near field capacity. Changing the water-regime when fruit picking commenced resulted in reduced growth and yield.

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REFERENCES.

Bacher, T. (1940). Forsøg med forskellige Vandmaengder til Tomater i Vaeksthus 1937–39. Beretning fra Statens Forsøgsvirksomhed i Plantekultur, Tidsskr. Planteavl., **44,** 692-9. Hort. Abstr., **13,** 524.

Bewley, W. F. (1928). Rep. Exp. Res. Sta., Cheshunt for 1927, 15.

——— (1950). Commercial glasshouse crops. London : Country Life.

Booer, J. R. (1953). The ring culture method. World Crops, **5,** 246.

Felföldy, L. (1951). Paradicsomfajták vizforgalmára vonatkozó élettani kisérletek. Agrok. Talajt., **1,** 85.

Frei, E. (1955). Transpiration and growth of sunflower plants as a function of the soil moisture tension. Trans. 5th int. Congr. Soil Sci. Leopoldville, 1954, **2,** 74.

Fröhlich, H. (1955). Pflanzenphysiologische Grundlagen der Zusatzberegnung im Feldgemüsebau. Dtsch. Gartenb., **2,** 134.

Gates, C. T. (1955). The response of the young tomato plant to a brief period of water shortage. I. The whole plant and its principal parts. Aust. J. biol. Sci., **8,** 196.

Hudson, J. P., and *Salter, P. J.* (1953). Effects of different water-regimes on the growth of tomatoes under glass. Nature, Lond., **171,** 480.

———, ———, and *Majmudar, A. M.* (1957). Water-regimes in irrigation research. Rep. 14th int. hort. Congr. Scheveningen, 1955, **1,** 497.

Kerr, E. A. (1952). The Bouyoucos moisture meter in greenhouse tomato culture. Bienn. Rep. Vineland hort. Exp. Stat. Prod. Lab. for 1951–52, 14.

Lambeth, V. N. (1954). Irrigation multiplies vegetable yields in Missouri. Market Gr. J., **83,** 8.

Leonard, E. R. (1953). Some preliminary observations on the growth inter-relations of roots and tops of glasshouse tomatoes. Rep. 13th int. hort. Congr. London, 1952, **2,** 885.

Majmudar, A. M., and *Hudson, J. P.* (1957). The effects of different water-regimes on the growth of plants under glass. II. Experiments with lettuces (*Lactuca sativa*). J. hort. Sci., **32,** 201.

Moen, O. (1938). Forsøk med undervanning til tomater i Hus. Meld. Norg. LandbrHøisk., 1938. Hort. Abstr., **8,** 1101.

Morris, L. G., Postlethwaite, J. D., Edwards, R. I., and *Neal, F. E.* (1953). The dependence of the water requirements of glasshouse crops upon the total incoming solar radiation. N.I.A.E. Tech. Memo. No. 86.

Murneek, A. E. (1926). The effects of correlations between vegetative and reproductive functions in the tomato. Plant Physiol., **1,** 3.

Rose, T. H., and *Dermott, W.* (1953). Soil moisture under glass OS/3. Unpublished interim reports of experiments/observation studies. 13-15. Ministry of Agriculture, Fisheries and Food, N.A.A.S., S.E. Province.

Ross, A. A. (1946). Studies of growth correlations in the tomato. Qd J. agric. Sci., **3,** 121.

Russell, E. J. (1950). Soil conditions and plant growth. 8th Ed. London : Longmans, Green.

Salter, P. J. (1954*a*). The effects of different water-regimes on the growth of plants under glass. I. Experiments with tomatoes (*Lycopersicum esculentum* Mill.). J. hort. Sci., **29,** 258.

Salter, P. J., (1954*b*). Watering tomatoes under glass. Univ. Nottingham Dep. Hort. Res. Rep. for 1954, 13.

Schleusener, P. E., Peikert, F. W., and *Carolus, R. L.* (1949). Results of irrigation on vegetable crops. Quart. Bull. Mich. agric. Exp. Sta., **31**, 343.

Searle, S. A. (1954). Plant climate and irrigation. Chichester : Chichester Press.

Veihmeyer, F. J., and *Hendrickson, A. H.* (1950). Soil moisture in relation to plant growth. Ann. Rev. Pl. Physiol., **1**, 285.

Went, F. W. (1944). Plant growth under controlled conditions. III. Correlations between various physiological processes and growth in the tomato plant. Amer. J. Bot., **31**, 597.

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THE VARIETAL RESISTANCE OF FRUITS TO BROWN ROT

II. THE NATURE OF RESISTANCE IN SOME VARIETIES OF CIDER APPLE

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THE first paper in this series (Byrde, 1956) described experiments on the susceptibility of a range of dessert, culinary and cider varieties of apple to infection by the brown rot fungus *Sclerotinia fructigena* Aderh. and Ruhl. In these studies two forms of resistance to the disease were apparent. Firstly, the rate of spread of the mycelium of the pathogen from an established infection was significantly lower in fruit of the culinary variety Edward VII than in the other varieties studied. Secondly, the " bitter-sweet " cider varieties Chisel Jersey, Dabinett and Yarlington Mill showed resistance to infection of freshly-made wounds by spores of *S. fructigena.* Furthermore, in an experiment using twenty representative varieties, a significant negative correlation was found to exist between spore infection of wounds and the rate of browning of the injured tissue. It was therefore suggested that, since the browning of injured tissues is known to arise through the enzymic oxidation of phenolic compounds in the fruit, such substances may play a part in resistance to brown rot.

A fuller investigation of the nature of brown rot resistance in cider apples has now been carried out, and the results are presented below.

MATERIALS AND METHODS.

Apples.

The cider varieties used in this series of experiments were as follows :

" *Sweet* " : Northwood, Sweet Alford, White Alphington.
" *Sharp* " : Fair Maid of Devon, Frederick.
" *Bitter-sweet* " : Chisel Jersey, Dabinett, Ellis Bitter, Kingston Bitter, Michelin, Reine des Pommes, Royal Jersey, Sherrington Norman, Tardive Forestière, Upright Médaille d'Or, Yarlington Mill.
" *Bitter-sharp* " : Foxwhelp, Kingston Black, Stoke Red.

In addition, the dessert variety Laxton's Superb was included in many tests, in view of its known susceptibility to brown rot (Wormald, 1954, p. 63).

Preparation of fruit juices.

The methods were substantially those described by Cole (1956).

Oxidized juice was obtained from freshly-gathered apples. These were passed through a stainless mincer and the minced tissue exposed to the air for several hours with frequent turning, to promote rapid oxidation. The tissue was then squeezed in a muslin bag and the juice so obtained was further oxidized by bubbling a stream of air through it. In some experiments, as noted later, the extract was cleared by centrifuging at 13,000 r.p.m. for 5 min.

Unoxidized juice. Cole's method of heat-treatment to inactivate oxidase enzymes present in apple juice does not preclude the subsequent oxidation of phenolic compounds in the juice by fungal polyphenol oxidase enzymes, but browning from this cause was comparatively slight in the single experiment in which unoxidized juice was used. Attempts to prevent oxidation of juices of " high-tannin " varieties by the addition of sodium cyanide, at a final concentration of $1 \cdot 16 \times 10^{-2}$M, instead of by heat treatment as described by Cole, were unsuccessful, presumably because of the very high phenol content and polyphenol oxidase activity of fruit of these varieties.

Assessment of flesh firmness.

Flesh firmness was assessed by estimating the pressure required to force a plunger of $\frac{1}{2}$ in. diameter into the flesh of the apple for a distance of $\frac{3}{16}$ in. The apparatus was initially used by Hinton (1932) and was based on the design of Murneek (1921). The fruit skin was removed before the test was applied, to eliminate differences in skin toughness. Three apples were used per variety.

Inoculation and browning tests.

The methods used followed those already described in Part I (Byrde, 1956).

In vitro *spore germination tests.*

These were carried out on cellulosed glass slides by a method similar to that used for routine fungicide tests (Byrde, 1952). A spore suspension of *S. fructigena* was prepared in distilled water and its concentration adjusted to 500,000 spores ml. by means of a haemocytometer.

The spore suspension (0·2 ml.) was mixed with the test solution (0·8 ml.) in a small test tube. After thorough mixing, drops were pipetted out on a cellulosed glass slide. As a control, spore suspension (0·2 ml.) was mixed with a sucrose-sodium citrate spore stimulant (0·8 ml.), the final concentrations in the drops being : sucrose, 0·1 per cent. ; sodium citrate, 0·001 per cent. ; spores, 100,000/ml. After incubation at 25° C. for 17 hr. the germination of 50 spores in each of two drops was recorded ; it was found necessary to dilute the drops and stain with cotton blue in lactophenol to see the spores in the dark brown liquid.

Preparation of fungal pectolytic enzymes.

The methods of Cole (1956) were followed, with slight modifications. Cultures of *S. fructigena* were grown on the following liquid medium : pectin, 1 gm. ; ammonium tartrate, 2 gm. ; KH_2PO_4, 0·1 gm. ; $MgSO_4 \cdot 7H_2O$, 0·05 gm. ; water, 100 ml. The medium was dispensed in 15 ml. lots in 4 oz. medicinal flats and, after sterilization, inoculated with a heavy spore suspension of *S. fructigena*. Spores were obtained from cultures on potato plugs soaked in 7·5 per cent. malic acid for 3 days before autoclaving (Wiltshire, 1920). The bottles were laid on their sides and incubated at 25° C. for 11 days, after which the mycelium was filtered off and the filtrates used for studies of pectolytic enzyme activity.

Estimation of pectolytic activity.

Maceration of plant tissues. The method used was similar to that initially developed by Brown (1915) and used by Cole. Cylinders of tissue were cut, by means of a 1 cm. cork borer, from cucumber or unripe apple fruits. These cylinders were

injected with water under the air pump and discs 0·26 mm. thick cut from them with a microtome. Six such discs were immersed in the test solution and tested for coherence after intervals of ten minutes by a gentle pull with two dissecting needles. The macerating activity of the preparation was defined as $\frac{100}{t}$ where t was the time (min.) for the discs to lose coherence.

For tests on the effect of fruit juices on macerating activity, the fungal filtrate was buffered to approximately pH 5·0 by the addition of Na_2HPO_4 and citric acid.

Reduction in viscosity of sodium pectate solution. The method used was similar to that outlined by Wood (1955) and was based on the reduction in viscosity of a 1·6 per cent. aqueous solution of sodium pectate. If t_{50} was the time (min.) required to reduce the initial viscosity of the solution by 50 per cent., the activity was expressed as V_{50}, where $V_{50} = \frac{100.}{t_{50}}$

For viscometric assay, 2 ml. of unbuffered fungal filtrate was incubated overnight at 25° C. with 2 ml. of centrifuged apple juice, 4 ml. of McIlvaine's citrate-phosphate buffer (pH 6·0) and 2 ml. of water. Controls were always included, with water instead of apple juice.

EXPERIMENTAL RESULTS.

Infection of wounds by spores.

Spore infection experiments were carried out on nine dates during the period July–November 1956, with the varieties Chisel Jersey, Dabinett, Yarlington Mill and Laxton's Superb, the last as a form of control (Table I). Following an angular transformation of the data (Anscombe, 1948), statistical analysis indicated that, as in earlier years, the three cider varieties showed a significant degree of resistance to spore infection ; Laxton's Superb was highly susceptible. Although the levels of infection on the nine dates differed significantly, these variations were not systematic, and it is not possible at this stage to put forward an hypothesis to account for them. Tests on spore germination and the inhibition of pectolytic enzymes carried out on any date during the period July–November were thus likely to be representative of the period as a whole.

Effect of spore load.

On 26th September 1956 an experiment was carried out to examine the effect of spore load on infection of wounds. Spore suspensions of 10,000, 3,200, 1,000 and 320 spores/ml. were prepared and applied to freshly-made wounds in the skin of the variety Yarlington Mill. The numbers of wounds (out of 10) showing brown-rot infection after 5 days were as follows : 10,000 spores/ml., 7 ; 3,200 spores/ml., 1 ; 1,000 spores/ml., 0 ; 320 spores/ml., 0. The resistance of wounds thus appeared to diminish under heavy spore loads.

Effect of glutathione.

Henze (1956) has shown that glutathione inhibits the enzymic browning of chlorogenic acid solutions. Preliminary tests showed that an aqueous solution (0·062M) of this compound prevented the browning of cut tissues of the cider varieties listed

TABLE I.

Number of brown rot infections following spore inoculation of ten wounds.

Variety	Date of inoculation									Total	Mean per-cent.	Mean of trans-formed data
	5th July	18th July	2nd Aug.	15th Aug.	29th Aug.	14th Sept.	26th Sept.	26th Oct.	7th Nov.			
Laxton's Superb	5	9	10	10	10	10	9	10	10	83	92	80·9
Dabinett	0	1	5	1	2	0	0	0	0	9	10	12·0
Chisel Jersey	0	0	4	5	7	5	0	0	5	26	29	25·7
Yarlington Mill	0	0	2	1	6	2	0	0	6	17	19	19·2
L.S.D. between means of transformed data : P = 0·05												13·0
P = 0·01												17·7
P = 0·001												23·7

above. Spore suspensions of *S. fructigena* (1,000 spores/ml.) were therefore made up in distilled water and in 0·062M-glutathione and applied to wounds made in apples of the resistant variety Yarlington Mill. The experiment was carried out on three dates; infection data, recorded after 5 days, are presented in Table II. Statistical analysis of the transformed data shows a significantly higher level of infection ($P < 0{\cdot}01$) where glutathione was present. There was no evidence of damage to the tissues when 0·062M-glutathione was applied, without spores, to wounds of this variety.

Similar results were obtained when fruits were dipped into water at 80° C. for 3 min., either before or after wounding, prior to inoculation.

Table II.

Number of brown rot infections following spore inoculation of ten wounds : Yarlington Mill.

Medium in which spores were suspended	Dates			
	22nd Aug.	29th Aug.	26th Sept.	Mean
Glutathione solution (0·062M)	8	10	4	7·3
Water only	1	6	0	2·3

Partial correlation of spore infection with browning rate and flesh firmness.

The 20 varieties of apple listed above were used for spore infection and browning rate tests on 14th September, and for a flesh firmness test on 21st September. Statistical analysis of the data, by the method of partial correlation, gave the following correlation coefficients, both of which were significant ($P = 0{\cdot}05$) :

Between infection level and logarithm of browning index, 0·47.

Between infection level and mean flesh firmness, 0·46.

It was felt that the direct correlations between infection level and browning, or flesh firmness, might be affected by variations in the other factor and that partial correlation, by eliminating these variations, was to be preferred.

Spore germination tests.

The percentage germination of spores of *S. fructigena* in oxidized juice of the variety Chisel Jersey and in sucrose-citrate spore stimulant (control) was as follows : oxidized juice, 98 per cent. ; control, 90 per cent. In another experiment, fruits of the variety Chisel Jersey were extracted with 0·1 M-phosphate buffer, pH 6·7, at the rate of 2 ml. buffer per gm. fruit tissue. The juice was allowed to oxidize and a very dark brown extract was obtained at the higher pH level. The percentage germination of *S. fructigena* spores was as follows : oxidized extract, 75 per cent. ; control, 81 per cent. There was no reduction in the length of germ tubes in the extract by comparison with the control.

Effect of apple juices on pectolytic enzymes.

Maceration.

One experiment was carried out in which the macerating activity of an enzyme preparation from *S. fructigena* was tested against discs of fruit tissue of the varieties Laxton's Superb and Yarlington Mill. Maceration activities were found to be as

follows : Laxton's Superb, 2·25 ; Yarlington Mill, 1·25. Apple discs are suitable for maceration studies only for a limited season and subsequent studies were carried out with cucumber discs which have been shown to give comparable results (Cole, 1956).

Batches of *S. fructigena* enzyme (5 ml.) were incubated overnight at 25° C. with oxidized juices of 5 varieties of apple (5 ml. each) and the macerating activity tested against cucumber discs. The activities were as follows : Laxton's Superb, 2·25 ; Sweet Alford, 1·67 ; Dabinett, 1·46 ; Yarlington Mill, 1·46 ; Chisel Jersey, 1·38 ; control (water), 2·50. Incubation of the enzyme with oxidized juices of the resistant cider varieties thus appeared to reduce its activity by the greatest amount.

In the next experiment, samples of a spore suspension of *S. fructigena* (1 ml.) were diluted with oxidized and heat-treated juices (9 ml.) of each of 5 varieties, buffered at pH 5·0 with McIlvaine citrate-phosphate buffer and incubated overnight at 25° C. ; the final concentration of spores was 146,000 ml. The macerating activity of the culture filtrates is shown in Table III and is seen to be very low by comparison with that of other *S. fructigena* filtrates (cf. Cole, 1956) ; the corresponding figure for spores germinating in a sucrose-citrate spore stimulant was 0·92.

TABLE III.

Macerating activity of culture filtrates containing germinating spores of S. fructigena.

Variety	Heat-treated juice	Oxidized juice
Laxton's Superb	0·92	0·77
Chisel Jersey	0·86	0·67
Sweet Alford	0·77	0·71
Dabinett	0·77	0·67
Yarlington Mill	0·73	0·67

Statistical analysis of the data of Table III shows that, though the differences between varieties were not sufficiently large to attain significance, the overall activity of the oxidized juices was significantly less (P = 0·05) than that for the heat-treated juices.

TABLE IV.

Effect of Yarlington Mill apple juice on cucumber discs and on S. fructigena *enzyme preparation ; maceration activities.*

Treatment of enzyme	Treatment of cucumber discs			Mean value
	Overnight in water	Overnight in oxidized juice	Freshly cut	
Mixed with oxidized juice and incubated overnight	2·9	2·3	2·3	2·50
Freshly mixed with oxidized juice	4·2	3·3	2·9	3·47
Mixed with water and incubated overnight ..	7·5	5·0	5·0	5·83
L.S.D. between means : P = 0·05				1·31
P = 0·01				2·17

The next experiment was designed to examine the mechanism of the inhibitory action of Yarlington Mill juice on the macerating activity of *S. fructigena* enzyme. The response of cucumber discs cut and immersed overnight in water or in oxidized Yarlington Mill apple juice was compared with that of freshly prepared discs. The buffered enzyme also received differential treatments: incubation overnight with oxidized Yarlington Mill apple juice; mixture with the juice immediately before assay; mixture with water and incubation overnight (control). All nine combinations of cucumber and enzyme treatments were tested, with the results shown in Table IV.

Statistical analysis of the data shows that different treatments of the cucumber discs had no significant effect on maceration, but that overnight incubation of the enzyme with the apple juice resulted in a significant loss of macerating activity ($P = 0{\cdot}01$). The activity of the freshly-mixed enzyme was intermediate.

In the final experiment, which was carried out in duplicate, 5 ml. samples of buffered enzyme were incubated overnight at 25° C. with 5 ml. of each of the following:

(1) water,
(2) gelatin solution (0·2 per cent.),
(3) a mixture of oxidized Yarlington Mill juice (4 parts) with water (1 part),
(4) gelatin-treated Yarlington Mill juice, prepared by adding 1 per cent. aqueous gelatin solution (1 part) to oxidized Yarlington Mill juice (4 parts) and removing the precipitate by filtration,
(5) gallotannin solution (0·2 per cent.).

Maceration activities at pH5 are shown in Table V. In one of the duplicate tests, centrifuged oxidized Yarlington Mill juice was included and the mixture with buffered enzyme showed the same macerating activity as the one with uncleared juice; the formation of a precipitate was clearly seen when the centrifuged juice was mixed with the enzyme.

Table V.

Maceration activities of S. fructigena *enzyme following different overnight treatments.*

Enzyme treatment	Mean macerating activity
Control (water)	7·50
Gelatin (0·2 per cent.)	7·50
Yarlington Mill juice (80 per cent.) ..	2·90
Gelatin-treated juice	6·65
Gallotannin (0·2 per cent.)	1·95
L.S.D. ($P = 0{\cdot}05$)	3·54

Pre-treatment of the Yarlington Mill juice with gelatin thus decreased its effect on the macerating enzyme.

Viscometric assay.

No appreciable reduction of polygalacturonase activity was obtained in a number of tests with oxidized juices. Values of V_{50} obtained in a typical experiment in which oxidized apple juices of the varieties Sweet Alford and Yarlington Mill were incubated

overnight with *S. fructigena* enzyme at 25° C. were as follows : Sweet Alford, 23·5 ; Yarlington Mill, 23·8 ; Control, 24·1. Attempts to increase the concentration of juices of high-tannin varieties in the system resulted in anomalous results in the " blanks ", apparently because of an effect of high concentrations of the juices on the sodium pectate substrate.

DISCUSSION.

In Part I (Byrde, 1956) it was suggested that the resistance of certain varieties of cider apple to infection by spores of *S. fructigena* might be associated with their high phenolic content. This hypothesis was put forward in view of the significant negative correlation obtained in 1955 between the level of spore infection and the rate of browning of injured tissue of 20 representative varieties of dessert, culinary and cider apples. A partial correlation of a similar nature has been obtained in 1956 (see p. 231), when 19 varieties of cider apple were examined alongside the highly susceptible dessert variety Laxton's Superb.

The chemistry of the browning of apple tissue is not fully understood but it is known to arise through the enzymic oxidation of polyphenols, of which chlorogenic acid has been shown to be one (Weurman and Swain, 1953) and *l*-epicatechin another (Siegelman, 1955). Moreover, it is currently thought that the browning process in plants may occur in two stages, viz. the oxidation of the simple polyphenols to quinones by the enzyme polyphenol oxidase, followed by polymerization to the brown " phlobaphenes ", tannin-like substances of high molecular weight (Hathway and Seakins, 1957). Resistance to brown rot might thus be associated with one or more of these components, each of which has been implicated in other studies on the chemical basis of resistance to plant disease. Thus Kirkham (1954) claimed that phenols played a part in the resistance of apple shoots to the scab fungus *Venturia inaequalis* (Cooke) Wint., and it has since been shown that chlorogenic acid, one of the simple phenols, is toxic to the fungus and is also effective against it *in vivo* (Kirkham and Flood, 1956). Similarly, chlorogenic acid, or quinones derived from it, were implicated by Johnson and Schaal (1952) in the resistance of potatoes to scab (caused by *Streptomyces scabies* (Thaxt.) Waks. and Henrici) and chlorogenic acid was subsequently shown to be toxic in culture, particularly at high pH levels where auto-oxidation readily occurs (Schaal and Johnson, 1955). The possible rôle of enzymatically formed quinones in the resistance of injured tissue to infection was first suggested by Szent-Györgyi and Vietorisz (1931). The phlobaphenes formed in leaves of resistant varieties of potato when attacked by *Phytophthora infestans* de Bary were considered by Müller and Behr (1949) to be involved in disease resistance in an unspecified rôle, and Nienstaedt (1953) concluded that resistance to chestnut blight (caused by *Endothia parasitica* (Murr.) A. and A.) may be related to tannins present in the bark of the chestnut.

Glutathione is known to inhibit the enzymic browning of chlorogenic acid, probably by reacting with quinones which are precursors of the brown substances (Henze, 1956). It has been shown above that 0·062M-glutathione solution also inhibits browning of apple tissue and that the resistance of the tissue to infection by spores of *S. fructigena* is at the same time reduced. This suggests that resistance is associated either with the phlobaphenes (which are not formed in the presence of glutathione) or with the quinone intermediates (which are inactivated by glutathione),

rather than with the unoxidized phenols, such as chlorogenic acid itself. This concept is supported by the fact that, while the varieties Chisel Jersey and Dabinett showed high resistance to infection by spores of *S. fructigena*, the mycelium of the fungus was able to penetrate uninjured (and hence initially unoxidized) tissues of these varieties at a rate not significantly different from that of the variety Laxton's Superb (Byrde, 1956).

The results of the spore germination experiments described above afford no evidence that resistance to spore infection arises from the direct fungistatic action of the fruit juices, either oxidized or unoxidized, on the spores of *S. fructigena*. In order to effect penetration of host tissue, however, *S. fructigena* is known to secrete a pectolytic macerating enzyme which breaks down the middle lamella (Cole, 1956). It seems probable that the negative partial correlation between spore infection and tissue hardness (cf. Willaman, Pervier and Triebold, 1925, working on plums) may be due to the greater resistance of hard tissue to maceration. But, in addition, substantial evidence has been presented to confirm the finding of Cole (1956) that the macerating enzymes of *S. fructigena* are deleteriously affected by apple juices. Examples of a similar kind for other fungi have been reported by Kieser, Pollard and Stone (1950) and by Weurman (1953). Moreover, a greater retardation of macerating action was achieved by oxidized juices of the resistant high-tannin cider varieties than by that of the variety Laxton's Superb, whilst activity of germinating spore suspensions of *S. fructigena* was significantly less in oxidized than in heat-treated juices (Table III).

Oxidized polyphenols in the injured tissue may thus play a part in varietal resistance to brown rot through their action upon the fungal macerating enzyme. They are probably of high molecular weight, since their effect is decreased by gelatin treatment. Moreover, the effect of oxidized Yarlington Mill juice on the macerating enzyme of *S. fructigena* is comparable with that of 0·2 per cent. aqueous gallotannin solution. Kertesz (1951, p. 356) cited conflicting evidence on the inactivation of fungal pectolytic enzymes by tannins and Kieser *et al.* (1950) reported the inhibition of a polygalacturonase from *Penicillium brevi-compactum* by both tannic acid solution (0·3 per cent.) and apple juice. It should not be assumed that the inhibitor demonstrated above is identical with that shown by Cole (1956) to be present in the juice of Bramley's Seedling apples.

There is clear evidence (Table IV) that the retarding agent in the oxidized juice of the variety Yarlington Mill acts directly against the macerating enzyme. It does not appear to increase the resistance of the plant tissue to maceration through the precipitation of host proteins by polyphenols in the manner thought to occur in the formation of humus (Handley, 1956). The effect is in fact parallel to that of tannic acid and plant tannins on viruses. Bawden and Kleczkowski (1945), for example, considered that tannic acid affected the virus and not the host, and Hirth (1951), supporting this conclusion, associated the inhibition of infectivity of tobacco mosaic virus with the formation at low pH of an insoluble complex with tannic acid.

Unexpectedly, no evidence was obtained of a comparable effect on fungal polygalacturonase as measured viscometrically. Two possible explanations may be put forward. It has been shown that the precipitation of virus protein by tannins is reversible and that infectivity of the virus can be restored by dilution with water (Thresh, 1956) ; it should be noted that the viscometric method involved considerable dilution of the oxidized juice. In addition, although Cole (1956), in studies on *S. fructigena* filtrates, found that maceration and polygalacturonase activity ran parallel,

it is possible that different enzymes are concerned, of which only the macerating enzyme is inhibited by the cider apple juices used. It is interesting to note that Kaji and Anabuki (1956) record that it is possible to separate the macerating and polygalacturonase enzymes of *Clostridium felsineum* var. *sikokianum* by means of ion-exchange resins.

On the basis of the data presented, it is therefore suggested that the resistance of certain high-tannin varieties of cider apples to spore infection by *S. fructigena* arises, at least in part, from the inactivation (probably through precipitation) of the fungal macerating enzyme by oxidized polyphenols of relatively high molecular weight. Such an hypothesis also takes into account the apparent breakdown of resistance in the presence of heavy spore loads (where enzyme secretion would be expected to be greater) and also as a result of heat treatment. The latter causes a softening of the tissues and also prevents the formation of oxidized phenols at the wound surface.

It is planned to carry out further investigations on the inhibition of the macerating enzymes of *S. fructigena*, particularly by the oxidation products of individual polyphenols, and it is hoped to report the results in a later paper in this series.

SUMMARY.

1. The bitter-sweet cider apple varieties Chisel Jersey, Dabinett and Yarlington Mill showed resistance to infection of fruit injuries by spores of *Sclerotinia fructigena* throughout the period July–November. Resistance to spore infection was partially correlated with the browning of the injured tissue and with the firmness of the apple flesh.

2. Treatment of injured tissue of the variety Yarlington Mill with 0·062 M-glutathione solution prevented browning and also reduced resistance to spore infection.

3. Oxidized juices of the variety Chisel Jersey showed no fungistatic activity towards germinating spores of *S. fructigena*.

4. Overnight incubation of oxidized juice of the variety Yarlington Mill with culture filtrates of *S. fructigena* markedly reduced the macerating activity of the latter towards cucumber discs; juice which had been previously treated with gelatin showed a much smaller effect.

5. There is strong evidence to suggest that the resistance to brown rot of certain high-tannin varieties of apple arises, at least in part, from reduction of the activity of fungal macerating enzymes by oxidized polyphenols, probably of high molecular weight, in the injured tissues. The latter substances probably act by precipitation of the enzyme and not by any effect on the plant cell.

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REFERENCES.

Anscombe, F. J. (1948). The transformation of Poisson, binomial and negative binomial data. Biometrika, **35,** 246.

Bawden, F. C., and *Kleczkowski, A.* (1945). Protein precipitation and virus inactivation by extracts of strawberry plants. J. Pomol., **21,** 2.

Brown, W. (1915). Studies in the physiology of parasitism. I. The action of *Botrytis cinerea*. Ann. Bot., **29,** 313.

Byrde, R. J. W. (1952). Experiments on the control of brown rot of apples and plums. I. Laboratory tests. J. hort. Sci., **27,** 130.

——— (1956). The varietal resistance of fruits to brown rot. I. Infection experiments with *Sclerotinia fructigena* Aderh. and Ruhl. on certain dessert, culinary and cider varieties of apple. J. hort. Sci., **31,** 188.

Cole, J. S. (1956). Studies in the physiology of parasitism. XX. The pathogenicity of *Botrytis cinerea, Sclerotinia fructigena* and *Sclerotinia laxa*, with special reference to the part played by pectolytic enzymes. Ann. Bot., N.S., **20,** 15.

Handley, W. R. C. (1956). Aspects of the significance of polyphenols in soil organic matter. Chem. and Ind., Nov. 10, 1956, p. 1301 (Abstract).

Hathway, D. E., and *Seakins, J. W. T.* (1957). Polyphenol oxidase oxidation of catechin, and an initial comparison of the polymer obtained with two tannins. Biochem. J., **65,** 32P.

Henze, R. E. (1956). Inhibition of enzymatic browning of chlorogenic acid solutions with cysteine and glutathione. Science, **123,** 1174.

Hinton, J. C. (1932). Studies on maturity of fruit. I. Introductory. II. Preliminary observations on the rate of softening of apples. Ann. Rep. Long Ashton Res. Sta. 1931, 40.

Hirth, L. (1951). Contribution à l'étude de l'inhibition du virus de la mosaique du tabac par diverses substances tanniques. Mode d'action de ces dernières. Ann. Inst. Pasteur, **80,** 458. Cited by Thresh (1956).

Johnson, G., and *Schaal, L. A.* (1952). Relation of chlorogenic acid to scab resistance in potatoes. Science, **115,** 627.

Kaji, A., and *Anabuki, Y.* (1956). Studies of macerating enzyme acting on middle lamella pectin. II. Adsorption of macerating enzyme and polygalacturonase on ion-exchange resin Duolite CS-101. Tech. Bull. Kagawa agric. Coll. (Japan), **7,** 222.

Kertesz, Z. I. (1951). The pectic substances (628 pp.). Interscience Publishers, New York and London.

Kieser, M. E., Pollard A., and *Stone, A. M.* (1950). The clarification of apple juice. II. The estimation of pectic enzyme activity. Ann. Rep. Long Ashton Res. Sta., 1949, 153.

Kirkham, D. S. (1954). Significance of the ratio between the water-soluble aromatic and nitrogen constituents of apple and pear in the host-parasite relationships of *Venturia* species. Nature, **173,** 690.

———, and *Flood, A. E.* (1956). Inhibition of *Venturia* spp. by analogues of host metabolites. Nature, **178,** 422.

Müller, K. O., and *Behr. L.* (1949). "Mechanism" of *Phytophthora*-resistance of potatoes. Nature, **163,** 498.

Murneek, A. E. (1921). A new test for maturity of the pear. Oregon agric. exp. Sta. Bull. no. 186, pp. 8-10.

Nienstaedt, H. (1953). Tannin as a factor in the resistance of chestnut, *Castanea* spp., to the chestnut blight fungus, *Endothia parasitica* (Murr.) A. and A. Phytopathology, **43,** 32.

Schaal, L. A., and *Johnson, G.* (1955). The inhibitory effect of phenolic compounds on the growth of *Streptomyces scabies* as related to the mechanism of scab resistance. Phytopathology, **45,** 626.

Siegelman, H. W. (1955). Detection and identification of polyphenoloxidase substrates in apple and pear skins. Arch. Biochem. Biophys., **56,** 97.

Szent-Györgyi, A., and *Vietorisz, K.* (1931). Bemerkungen über die Funktion und Bedeutung der Polyphenoloxydase der Kartoffeln. Biochem. Z., **233,** 236.

Thresh, J. M. (1956). Some effects of tannic acid and of leaf extracts which contain tannins on the infectivity of tobacco mosaic and tobacco necrosis viruses. Ann. appl. Biol., **44,** 608.

Weurman, C. (1953). Pectinase inhibitors in pears. Act. bot. Neerl., **2,** 107.

———, and *Swain, T.* (1953). Chlorogenic acid and the enzymic browning of apples and pears. Nature, **172,** 678.

Willaman, J. J., Pervier, N. C., and *Triebold, H. O.* (1925). Biochemistry of plant diseases. V. Relation between susceptibility to brown rot in plums and physical and chemical properties. Bot. Gaz., **80,** 121.

Wiltshire, S. P. (1920). The production of conidia in pure cultures by the brown rot fungus of the apple. Ann. Rep. Long Ashton Res. Sta. 1919, 34.

Wood, R. K. S. (1955). Studies in the physiology of parasitism. XVIII. Pectic enzymes secreted by *Bacterium aroideae.* Ann. Bot., N.S., **19,** 1.

Wormald, H. (1954). The brown rot diseases of fruit trees. Min. Agric. Tech. Bull. no. 3 (113 pp.). H.M. Stationery Office, London.

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THE BEHAVIOUR OF SOFTWOOD CUTTINGS OF APPLE IN THE OPEN UNDER INTERMITTENT MIST AND IN A CLOSED PROPAGATION FRAME

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In 1927 Knight and Witt reported upon the performance of softwood cuttings of apple, plum and cherry rootstocks at East Malling. These cuttings had been collected at different times in the growing season and from various cultural sources, and all were set in closed frames with bottom heat of 65–70° F. With the discovery of synthetic growth substances as aids to rooting, the investigations were renewed and in 1939 Pearse, using the same rooting conditions as Knight and Witt, described his experiments with softwood cuttings of a range of fruit tree rootstocks. He obtained overall benefit from the use of growth substances but the extent of this effort depended upon the source and condition of the cutting. Because of the limited practical application of the closed frame method for rootstock propagation the studies were not extended.

Following the development of propagation under mist, interest in leafy cuttings has revived and the installation of mist frames in the open at East Malling has enabled the traditional method to be compared with this new technique. The resulting experiments have helped to explain certain seemingly contradictory findings of the earlier work.

Material and methods.

The rootstocks used in this investigation ranged from vigorous to dwarfing in character and included the vigorous Malling Crab C, the moderately vigorous 3436 and the dwarfing 3431, the two latter among those bred by crossing M.IX with a range of other rootstocks varieties (Tydeman, 1943). Crab C was available both in a stoolbed and as a hedge and cuttings were taken from both these sources. The other two rootstocks were available only from two-year bedded plants.

Cuttings were planted in three environments, viz. open-air frames with intermittent mist sprayers, with and without shading, and a closed propagation frame. The mist frames were controlled by a hydrostat and their development, construction and use have been described elsewhere (Singh, Rogers and Slater, 1957). Preliminary experiments had indicated the need for partially shading the open-air frames and, therefore, shaded and unshaded mist frames were both tested, the shading reducing light intensity to a half. The closed frame within a glasshouse was given bottom heat electrically, with temperature of the rooting medium controlled at 65° F. which, in 1956, was about 10° F. higher than in the mist frames.

Cuttings were collected and planted in the last week of May, June and July ; on the first occasion the source shoots were actively growing and very soft, on the second

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they were still growing but were less soft, on the third they were about to cease growth. The cuttings, about 6 to 7 cm. long, were from the tips of the shoots and were collected directly from the parent plant, i.e. no further cut was made, unless the lowest leaf was too near the base in which case it was removed.

The bases of all cuttings were treated with growth substance, viz. a quick dip in indole-3-butyric acid solution, specification ½ mg. per ml. 50 per cent. alcohol (Hatcher and Garner, 1951). Cuttings were planted singly in 2½-inch fibre pots, filled with a mixture of equal parts of coarse sand and peat and placed in wooden trays each holding 28. Experimental plots consisted of 14 pots and the four kinds of cuttings were randomized within a block of two trays, with fourfold replication. Ten cuttings of each unit were experimental, making 40 for each treatment, and the remainder were used for periodic examination, one plant being lifted from each replicate at fortnightly intervals beginning three weeks after planting.

The cuttings in the propagation frame were hardened by gradually increasing ventilation and at eight weeks these, along with those from the mist, were placed in partial shade. Here they were hand watered, starting with five waterings and reducing to one per day by the end of the week.

At nine weeks from the initial planting, cuttings were examined. Those that had rooted were replanted in John Innes potting compost. After a further week in partial shade they were lifted, with compost still adhering, and planted in the open.

Results.

Percentage of cuttings rooted.

The results are summarized in Table I. Analysis of variance showed that the effects of environment, occasion of planting, source of cutting, and their first order interactions, were all significant.

Environmental differences were distinct, with excellent rooting in shaded mist and marked failure in the closed frame. Performance in unshaded mist was intermediate.

Early planting in mist was more effective than later planting, but not in the propagation frame. In shaded mist on the first occasion the mean percentage rooting for all cuttings was 84·4, but the same soft actively-growing tissues which here rooted

Table I.

Percentages of rooted cuttings.

Environment	Time of planting	Crab C		3436	3431	Mean	General mean
		Stool	Hedge	Bedded plants			
Shaded mist	May	100	83	88	68	84·4	
	June	100	83	65	33	70·0	
	July	83	80	50	5	54·4	69·6
Unshaded mist	May	90	50	43	20	50·6	
	June	68	55	0	0	30·6	
	July	53	63	33	0	36·9	39·4
Propagation frame ..	May	0	0	0	0	0	
	June	3	33	0	0	8·8	
	July	30	28	0	0	14·4	7·7
	Mean	58·3	52·5	30·8	13·9		

so well succumbed altogether to an infection of *Botrytis* in the propagation frame. Later planted cuttings in the shaded mist rooted progressively less, but in the closed frame survived better and rooted correspondingly more. These opposite trends in the two environments are characteristic of their respective conditions for survival. When these are favourable, as in shaded mist, there is full scope for rooting. In less favourable conditions, however, such as in unshaded mist, the effective behaviour of the cutting is a compromise determined by the survival factor.

In the shaded mist, the minimum rooting with May planting was 68 per cent. by the dwarfing 3431 rootstock, and the maximum was 100 per cent. by cuttings from stool shoots of the vigorous Crab C. In June Crab C still rooted excellently, but 3431 had declined to 33 per cent., and 3436 was intermediate. The July cuttings showed this differential decline still more clearly, the range being from 83 to only 5 per cent.

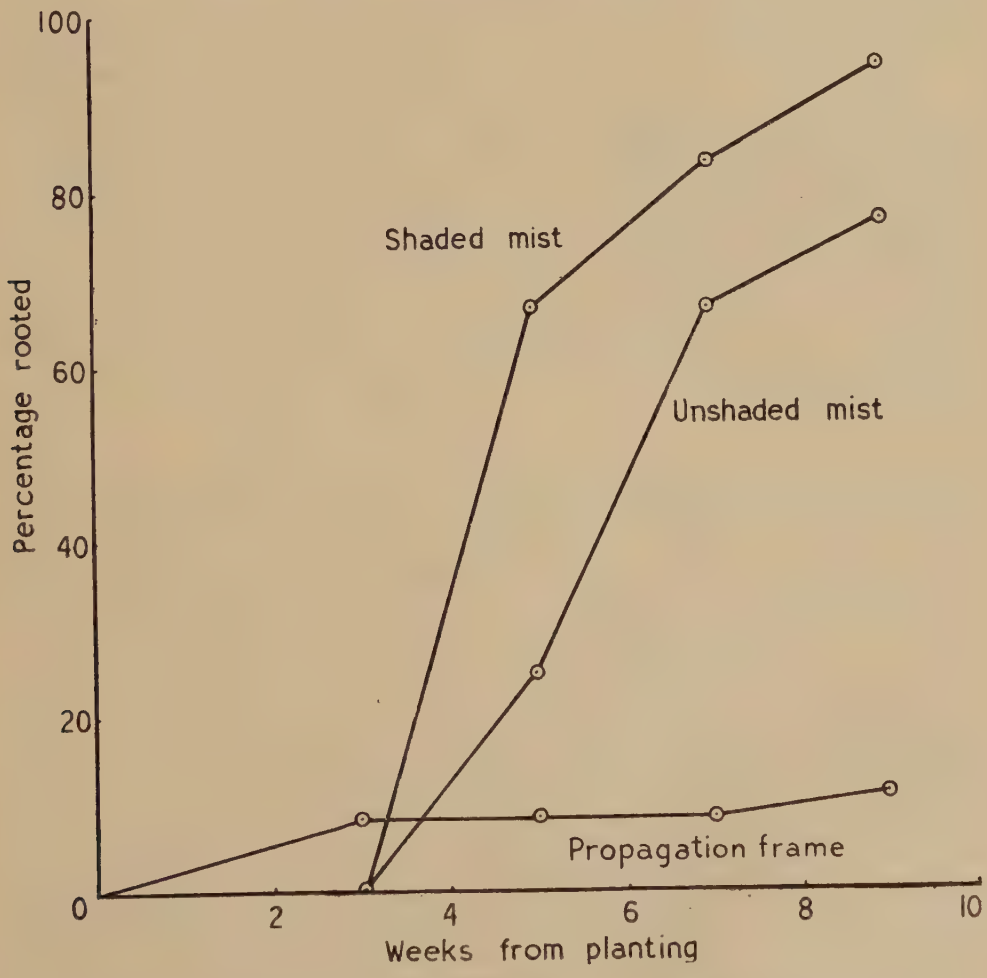

FIG. 1.

Rooting of cuttings of Crab C stool shoots in different environments (means of 3 series).

A comparison of the stool and hedge sources of Crab C shows that both rooted well in shaded mist. In unshaded mist, however, the stool shoots were much better; but whereas cuttings from this source rooted less freely as the season went on, hedge cuttings taken later maintained and even improved their rooting. In the propagation frame only Crab C rooted at all but, with June planting, hedge cuttings rooted better than stool cuttings. These rooting results are better understood in the light of the periodic observations summarized in Table II. With all types of cuttings the same environmental contrasts are evident, a higher percentage of rooting being usually associated with an early appearance of roots. The time relations of rooting in the three environments are clearly seen when the values for the vigorously rooting Crab C stool cuttings are plotted (Fig. 1). In the mist frames, rooting did not begin until the fourth or fifth week, by which time 67 per cent. were rooting under shade compared with 25 per cent. without shade ; in contrast, in the propagation frame a few cuttings were showing roots after as little as three weeks, but these were almost the only ones to survive. Some hedge cuttings of Crab C also formed roots in the closed frame, these being limited to later plantings when survival was somewhat improved.

Comparing the different types of cutting, Fig. 2 shows the mean rooting values for all occasions and environments. It will be seen that Crab C stool cuttings, which gave the highest total percentage rooting, were also the first to show roots. Furthermore, the similarity in the order of the various sources in the first appearance of roots and in their total progress, in fact the whole trend of the rooting curves, suggests that behaviour was governed by time relations. The poor source with a low ultimate rooting value simply had received insufficient time to root, as is clearly shown by other data on rootstock 3431 (Table II). At 9 weeks the average rooting was only 14·0 per cent., at 14 weeks this had reached over 50 per cent., with environmental values ranging from over 90 per cent. in shaded mist to complete failure in the propagation frame.

TABLE II.

Progress of rooting as shown by percentage rooted after different periods (average of all 3 series).

Variety and source	Environment	3 weeks	5 weeks	7 weeks	9 weeks	(14 weeks)
Crab C stool	Shaded mist	0	67	83	94	
	Unshaded mist	0	25	67	70	
	Propagation frame	8	8	8	11	
Crab C hedge	Shaded mist	0	8	75	82	
	Unshaded mist	0	17	25	56	
	Propagation frame	0	0	8	20	
3436, 2-year bedded ..	Shaded mist	0	17	25	68	
	Unshaded mist	0	0	17	25	
	Propagation frame	0	0	0	0	
3431, 2-year bedded ..	Shaded mist	0	0	25	35	93*
	Unshaded mist	0	0	0	7	64*
	Propagation frame	0	0	0	0	0*

* From another experiment.

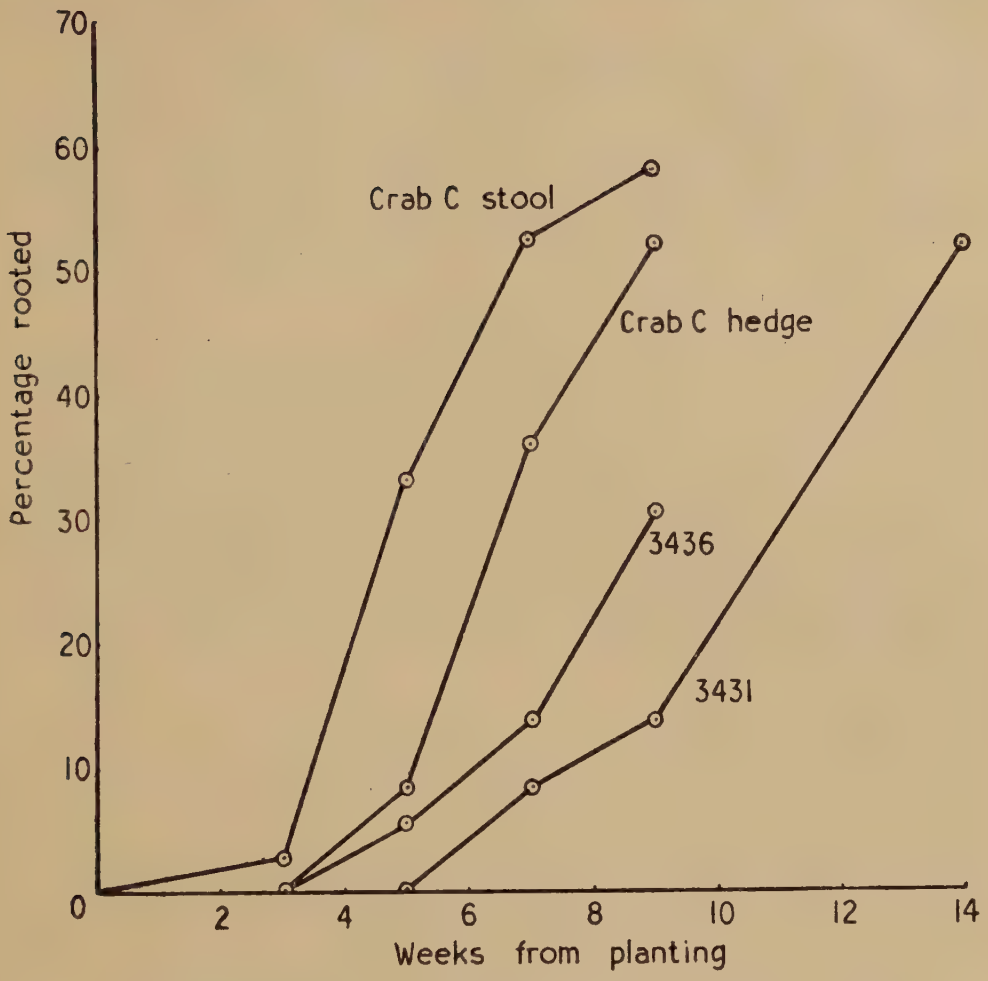

FIG. 2.

Rooting of cuttings from different sources (means of all series and environments).

Amount of root formed.

In respect of the number of roots formed, differences were generally similar to those described for percentage rooting but were very much sharper (Table III). Cuttings under shaded mist produced more roots than under unshaded mist, with a diminution with time in all sources excepting Crab C hedge. Again Crab C formed most, and 3431 least, roots. In the propagation frame, only a few cuttings from the later plantings rooted, again showing an improvement associated with better survival.

An outstanding feature was the extreme vigour of the Crab C stool shoot cuttings taken in May, which produced an average of 17·3 roots under shaded mist, in contrast to 2·4 for the dwarfing 3431 from bedded plants, Again, in parallel with the percentage rooting, those cuttings under mist which produced the most roots were those in which roots first appeared.

TABLE III.

Number of roots per cutting.

Environment	Time of planting	Crab C		3436	3431	Mean	General mean
		Stool	Hedge	Bedded plants			
Shaded mist	May	17·3	6·0	5·2	2·4	7·7	
	June	10·5	4·4	2·7	2·0	4·9	
	July	7·0	5·8	2·8	1·0	4·2	5·6
Unshaded mist	May	8·3	2·6	3·1	1·9	4·0	
	June	4·5	3·0	—	—	3·8	
	July	3·0	3·6	3·8	—	3·5	3·8
Propagation frame ..	May	—	—	—	—	—	
	June	5·0	3·8	—	—	4·4	
	July	7·9	5·5	—	—	6·7	5·6
	Mean	7·9	4·3	3·5	1·8		

Data for root lengths (Table IV) showed a similar trend but with certain modifications. Shaded mist was better than unshaded mist though less markedly so, with May cuttings making much greater growth than those taken subsequently. In the propagation frame the few cuttings which did root made relatively good growth, with an improvement with time.

Transplanting the cuttings.

In this paper it is not the intention to consider the behaviour of the rooted cuttings after transplanting, but some observations made in moving them should be put on record.

It was found that when the early batches of leafy cuttings were removed from the frames in August or September, the leaves were liable to scorch —especially those of

TABLE IV.

Length of longest root (mm.).

Environment	Time of planting	Crab C		3436	3431	Mean	General mean
		Stool	Hedge	Bedded plants			
Shaded mist	May	95	36	65	33	57	
	June	40	13	21	9	21	
	July	29	17	35	25	27	35
Unshaded mist	May	57	17	62	34	43	
	June	18	18	—	—	18	
	July	9	18	29	—	19	27
Propagation frame ..	May	—	—	—	—	—	
	June	32	26	—	—	29	
	July	64	50	—	—	57	43
	Mean	43	24	42	25		

the cuttings from shaded mist. This is probably associated with the condition both of the leaves and of the roots. Roots formed in the mist frames were thick, fleshy and at first devoid of root hairs, as opposed to the thin fibrous roots formed in the propagation frame. Under the moist conditions of the frames there is little need for water absorption. Thus the change to field conditions tends to provide a severe shock to the plant and careful hardening before transplanting is essential. This may be achieved by progressively opening the heated frame over a period of days or, in mist, by gradual reduction of the spray and removal of the shade.

DISCUSSION.

These trials have given useful information on rooting behaviour of softwood cuttings under mist and in propagation frames, and on the reasons for the superiority of the former and the limitations of the latter.

Under shaded mist, cuttings remained in perfect condition throughout the experiment and those planted there in May, when the source shoots were growing rapidly, themselves continued to grow and by the eighth week had doubled in length. Cuttings planted in June elongated less and those taken in July, from shoots which themselves had ceased growth, subsequently made no growth. Under these conditions they doubtless expressed their real rooting potentiality, in no way complicated by differential survival, the outstanding effects being the falling off in rooting with increasing hardness of the cuttings as planting became later, and the pronounced effect of the cultural source.

Cuttings in unshaded mist also maintained the turgidity of their leaves for a very long time but nevertheless suffered from scorching. In normal weather this was gradual and insidious, but on very sunny days the leaves became suddenly and severely scorched. It was interesting to note the differential reaction of the rootstocks : 3431 upcurled its leaves and the colour of their outer margins changed to light green ; the leaves of 3436 became slightly brown ; but in Crab C from both sources the leaves turned a deep pink. There was also a slow breakdown in the chlorophyll of the stems, which assumed in time the colour of the leaves. Furthermore, there was a direct relationship between scorching and the softness of the leaves, and cuttings taken later in the season were much less damaged. Such damage interfered with the expression of rooting potentiality.

In the propagation frame soft cuttings were prone to damage from *Botrytis* and the increase in rooting as the season advanced, in contrast with the declining gradient under mist, was the outcome of greater resistance to this disease. But, as survival was best in cuttings with the weakest capacity for rapid rooting, the overall result was very poor.

At this point it is useful to look at the earlier results of Knight and Witt (1927) and Pearse (1939). Their experiments, which included softwood cuttings of apple, were in the warm humid conditions of the closed frame, where, as we have seen, the overriding factor is survival. Knight and Witt found that cuttings which had ceased to grow rooted best and, in consequence, they considered the growth condition of the source shoot to be of prime importance, vigorous growth resulting from hard pruning being regarded as unfavourable. They did not stress the failure to survive, even though some batches of apple cuttings rotted soon after planting. In concluding that the non-active shoot was superior in rooting to the actively growing one, Knight and

Witt had not appreciated that this was due to its superior survival. With the aid of growth substance treatment, Pearse succeeded in rooting cuttings from shoots both in active and in non-active growth. He also used cuttings from different sources and his data reveal a strong superiority of stool shoots over shoots from bedded plants which was evident whether such cuttings were " active " or " stopped ".

There is no doubt about the importance of source, and the outstanding cuttings in the present experiments were those from stool shoots. Four types of cutting were compared, from three cultural sources and three different rootstocks, so care must be exercised in assessing both source and varietal influences. Yet Crab C cuttings from stools were superior to hedge shoots of the same rootstock, and markedly so to cuttings of 3436 and 3431 from bedded plants. Basically these different cuttings had different time requirements for rooting and 3431 cuttings, which were the last to start rooting under mist (failing altogether in the propagation frame), improved to give over 90 per cent. rooting in 14 weeks under shaded mist. This emphasizes the great value of mist, in which even material of low rooting capacity is able to root successfully if given sufficient time, time which is not available in the propagation frame because of the limitation of survival.

The rootstocks Crab C, 3436 and 3431 range from vigorous to dwarfing and they fall in the same order in their rooting capacities (Tables I and II). A direct relationship between the rooting of leaf-bud cuttings and vigour of the source shoot was also apparent (Singh, Garner and Hatcher, 1957). When growth was most rapid, as in early summer, the rooting response was greatest, with subsequent decline both in growth of the shoot and the rooting of the cutting taken from it. The effect of cultural source may also be interpreted in these terms and the hedge is of particular interest because it represents a condition intermediate between that of the stool and the bedded plant. The hedge as a cutting source is very important (Garner and Hatcher, 1955), for it is the ideal means of providing large numbers of cuttings, either from the shoot when still growing or later when dormant. The gradual transition from active growth in early summer to dormancy in late autumn involves a gradual diminution of capacity for immediate rooting (Garner and Hatcher, 1957), but one accompanied by a parallel increase in power to survive. Fortunately for the propagator, as the shoot approaches dormancy it amasses metabolic reserves enabling the cutting to initiate roots while its buds are dormant, this being the underlying principle of the hardwood cutting.

These experiments with softwood cuttings have involved the use of terminal portions of the source shoot, including the tip and several young leaves. In the parallel experiments with leaf-bud cuttings already referred to, the leaves used were lower down the shoot and their better survival accounts for their greater success in the propagation frame. If the leaf-bud cuttings are taken from higher up the shoot their survival is negligible and they fail to root (Garner *et al.*, 1954).

To revert in conclusion to the environmental comparison, which was one of the principal objects of the investigation, it is noteworthy that the best conditions for rooting were those in which the incident light was reduced by shading, and where no bottom heat was applied. Though, in consequence, rooting under shaded mist was not rapid, this was balanced by the persistent freshness of the cuttings over many weeks. The practical application of this technique depends on satisfactory transference of the rooted cuttings to the open nursery. No difficulty should arise if they are transplanted when dormant, but this limits the frames to one set of cuttings per season. The liability of leaves to scorch, if the cuttings are transplanted when still

leafy, needs further study ; if this difficulty is overcome, the application of the softwood cutting method may be considerably widened.

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The authors acknowledge the guidance and encouragement of Dr. W. S. Rogers in the course of these studies. The first author expresses his appreciation of the opportunity to spend a year at East Malling, which was given by Balwant Rajput College and Agra University and by the Government of India.

SUMMARY.

Softwood cuttings of apple from several sources were taken at three periods of the year, given growth substance treatment and propagated in different environments.

Intermittent mist with partial shade provided the best conditions for the full expression of rooting capacity ; the cuttings continued to grow and had time for rooting. In an unshaded frame, rooting was checked to some extent by leaf-scorching.

In a closed propagation frame with bottom heat the limiting factor was survival.

Rooting declined with the hardening of the source shoots as the season advanced.

Cuttings from stool shoots rooted better than those from bedded plants ; hedge cuttings were intermediate.

Speed and degree of rooting were associated directly with vigour of the source plant, whether inherent in the variety or induced by cultural methods.

Transference of the leafy cuttings to the open nursery needs further study.

REFERENCES.

Garner, R. J., and *Hatcher, E. S. J.* (1955). The influence of source and growth substance on the behaviour of apple and plum cuttings. J. hort. Sci., **30,** 116–28.

———, ——— (1957). The interplay of factors influencing rooting of shoot cuttings. Rep. 14th int. hort. Congr. 1955, 204-14.

———, ———, and *Nicoll, Catherine P.* (1954). Experiments with apple leaf-bud cuttings. Rep. E. Malling Res. Sta. for 1953, 145–9.

Hatcher, E. S. J., and *Garner, R. J.* (1951). Aspects of rootstock propagation. II. The development of the concentrated dip method of treating hardwood cuttings with growth substances. Rep. E. Malling Res. Sta. for 1950, 116–21.

Knight, R. C., and *Witt, A. W.* (1927). The propagation of fruit tree stocks by stem cuttings. II. Trials with hard and softwood cuttings. J. Pomol., **6,** 47–60.

Pearse, H. L. (1939). Experiments with growth controlling substances. II. Response of fruit tree cuttings to treatment with synthetic root-forming substances. Rep. E. Malling Res. Sta. for 1938, 157–66.

Singh, S. M., Garner, R. J., and *Hatcher, E. S. J.* (1957). The influence of source and environment on the performance of apple leaf-bud cuttings. J. hort. Sci., **32,** 248-53

———, *Rogers, W. S.*, and *Slater, C. H. W.* (1957). Mist propagation frames for leafy cuttings. Rep. E. Malling Res. Sta. for 1956, 54–9.

Tydeman, H. M. (1943). Further studies on new varieties of apple rootstocks. J. Pomol., **20,** 116–26.

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THE INFLUENCE OF SOURCE AND ENVIRONMENT ON THE PERFORMANCE OF APPLE LEAF-BUD CUTTINGS

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In a previous paper (Garner, Hatcher and Nicoll, 1954) experiments were described showing that leaf-bud cuttings of certain apple rootstock varieties could be rooted in a closed propagation frame supplied with bottom heat. Growth substance treatment was essential, as was a small heel of stem tissue in which new roots formed, but the axillary bud did not aid regeneration and could be excised at the outset. The resulting leaf-root system was finite, incapable of shoot growth (unless this followed bud initiation directly in the root), which indeed was the purpose of the experiment, viz. to provide such a system for physiological studies of leaf metabolism.

Rooting behaviour of these cuttings was influenced by the position of the leaf on the source shoot, by the time of its separation, and it varied markedly from year to year. It was clear that both source and climatic factors were involved.

Working with a different apple rootstock Nelson (1955) observed a similar source effect, leaf-bud cuttings from stoolbed shoots rooting more readily than those from bedded plants. Furthermore, Nelson found that continuous mist conditions in the open gave better rooting than other environments.

The present paper describes two trials. Trial I compared the effect of four sources on rooting of apple cuttings in a closed propagation frame and Trial II the performance of shoots from a stoolbed and from plants bedded in the nursery, in a closed frame and under intermittent mist in the open.

These trials have confirmed the superiority of the stoolbed source and the benefits of mist, and have also helped to explain the general behaviour of leaf-bud cuttings.

Trial I.

Experimental procedure.

On 23rd June 1954, leaf-bud cuttings of M.V apple rootstock were taken from growing shoots of four cultural sources: (i) an established stoolbed, with shoots earthed up in the normal manner, (ii) another section of the same stoolbed in which the shoots were not earthed up, (iii) two-year bedded plants previously winter-pruned with new growth arising well above the ground, (iv) three-year bedded plants similarly pruned. The leaves used were from the middle of the shoot, the fifth to the ninth from the top. The cuttings were sliced from the shoot by a shallow cut as in normal bud-grafting, to include a small heel of stem and the axillary bud. All cuttings were dipped at their base in growth substance solution (quick dip of indole-3-butyric acid, specification $\frac{1}{2}$

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mg./per ml. 50 per cent. alcohol) and planted in seed boxes in a mixture of equal parts of coarse sand and peat. The unit plot was a row of ten cuttings and the four source treatments were randomized in a box to form a block, with six-fold replication, altogether 60 cuttings for each treatment. The boxes were placed in a propagation frame in a glasshouse and bottom heat was supplied electrically to give a temperature of 65° F. One month later the cuttings were recorded for rooting.

Results.

The percentages of cuttings which rooted are shown in Table I. Of the four sources of M.V, those which rooted best were from normally-earthed stoolbed shoots ; where they were not so earthed, only half as many rooted. There was no difference between cuttings from two- and three-year bedded plants, which proved extremely poor sources. The general level of rooting was low compared with the results of earlier experiments (Garner *et al.*, 1954).

TABLE I.

Trial I. Percentage of cuttings of M.V rooted.

Source	Stoolbed		Bedded plants	
	Earthed	Not earthed	2-year	3-year
Percentage rooted	33·3	16·7	1·7	3·3
Mean	25·0		2·5	

Two- and three-year bedded plants not significantly different.

TRIAL II.

Experimental procedure.

On 28th June 1956, leaf-bud cuttings were planted in the heated propagation frame as in Trial I and in an open frame, sprayed intermittently, with partial shading which reduced the light intensity to a half (Singh *et al.*, 1957). In the latter, bottom heat was not supplied. The rootstocks were 3430 (vigorous) and 3436 (moderately vigorous) (Tydeman, 1943) and the sources were a normally earthed stoolbed and two-year bedded plants. After the same growth substance treatment as in Trial I, the cuttings were planted singly in 2½ inch fibre pots, again in sand and peat. The pots were packed in wooden trays, 28 in each. Each experimental plot contained fourteen pots, two trays with four randomized source plots forming a block. Within a plot, the two inner rows of five cuttings were experimental ; the outer row of four was used for periodic examination to study the course of rooting. There were four replicates giving 40 experimental cuttings per treatment which were finally examined and recorded after ten weeks.

Results.

These are set out in Table II. The overall effects on rooting of the three main factors—rootstock variety, cultural source and environment—were statistically significant. Comparison of rootstocks shows that the more vigorous 3430 rooted

better than 3436 and that, within each variety, cuttings from the stoolbed were far superior to those from bedded plants.

These effects were evident in both environments but, on the whole, rooting under mist was better than in the propagation frame. There were also significant interactions between the main factors, for it was the inferior cuttings, whether in relation

TABLE II.

Trial II. Percentage of cuttings rooted.

Environment	Rootstock*		Source†		Mean
	3430	3436	Stoolbed	Bedded	
Propagation frame ..	43	23	64	2	33
Mist frame	54	39	64	29	47
Mean	49	31	64	16	

* Including both sources. † Including both rootstocks.

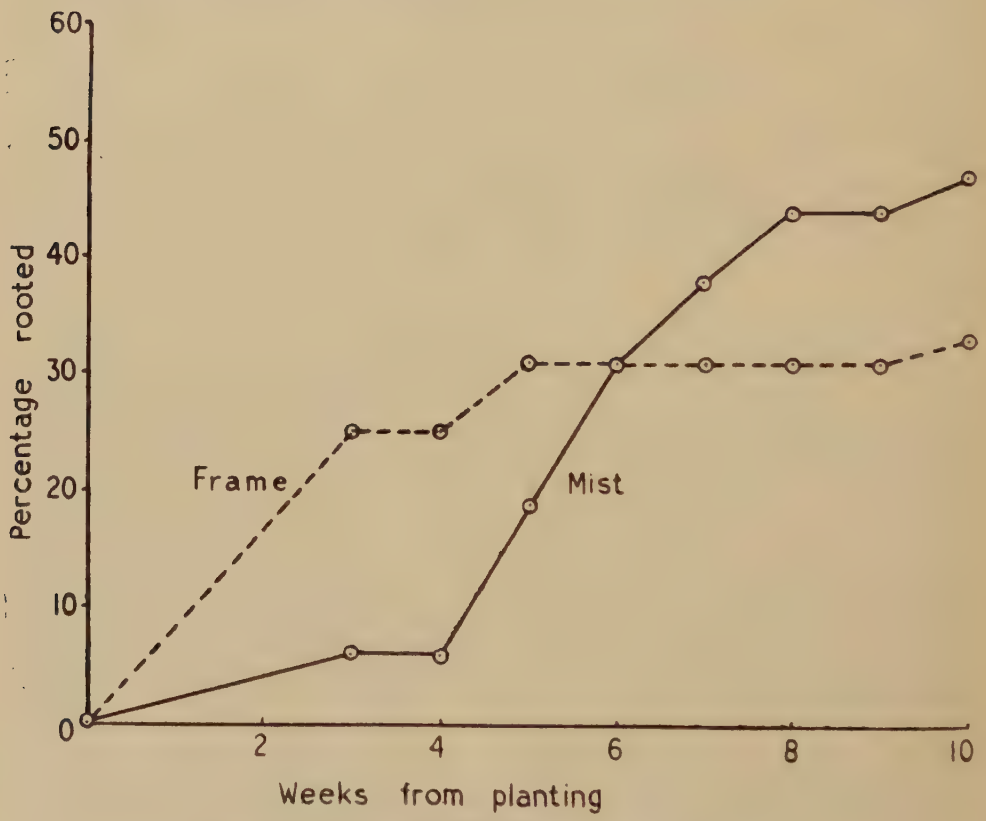

FIG. 1.

Rooting of apple leaf-bud cuttings in two environments.

to rootstock variety or cultural source, which benefitted most from the more favourable conditions. In contrast, leaf-bud cuttings from stool shoots rooted equally well in both environments.

The speed of rooting, as shown by periodic observations on sample cuttings, was related to differences in cutting environment. In the propagation frame rooting progressed rapidly from the beginning and was completed within five weeks, whereas under mist it began slowly but after some four weeks proceeded briskly (Fig. 1). In a further two weeks the cuttings had, in number rooted, overtaken those in the closed frame, subsequently going well ahead.

As far as cuttings from stoolbed shoots are concerned, the environmental difference was essentially a matter of timing and not of final number rooted, for this was similar (Fig. 2). Cuttings from bedded plants, however, with a single exception, all died within a few weeks in the propagation frame, without rooting ; whereas

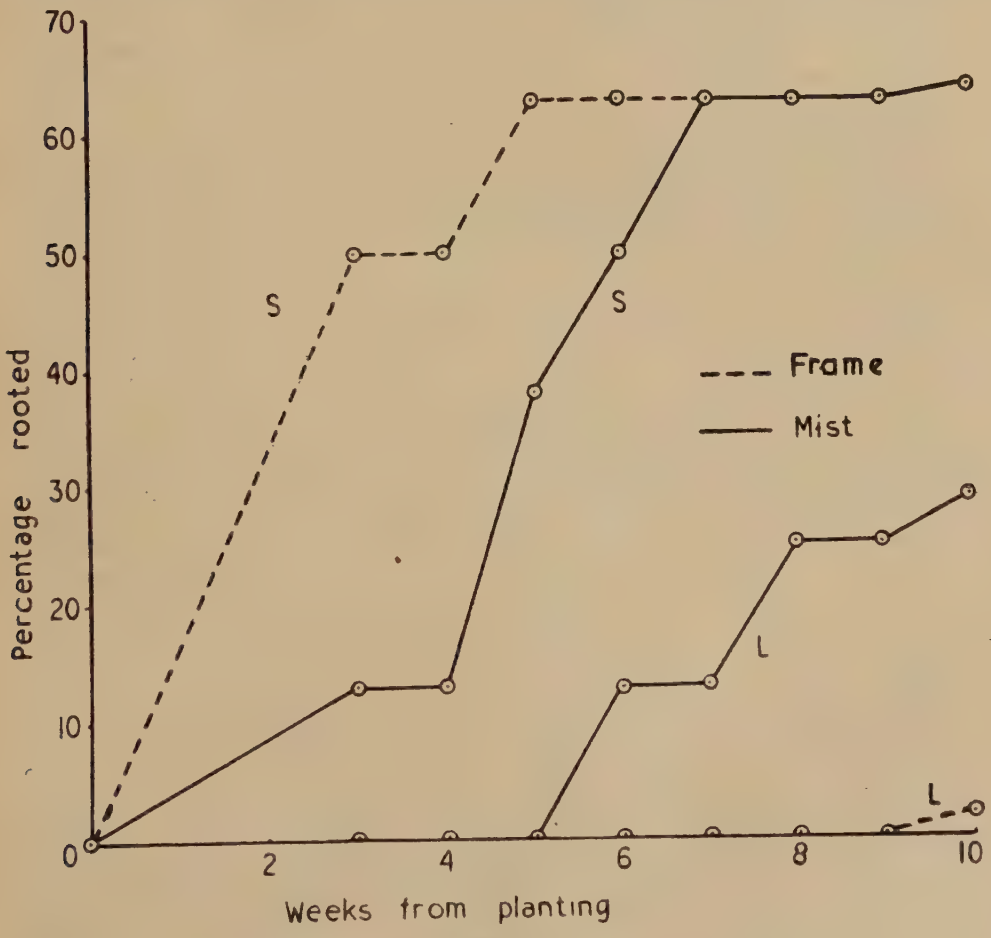

FIG. 2.

Rooting of apple leaf-bud cuttings, from stool (S) and lined-out (L) nursery plants, in two environments.

under mist, though no rooting was discernible for five weeks, 29 per cent. had rooted by the end of the experiment.

The amount of rooting, as measured by number and length of roots, was similar for the two rootstocks from both sources. The only marked difference was environmental, cuttings which succeeded in rooting in the closed frame being more advanced than their counterparts in the mist frame. The former averaged 3·1 roots per cutting and a maximum length of 191 mm., the latter only 1·9 roots and 74 mm.

DISCUSSION.

These experiments have brought out clearly the importance of the source from which the leaf-bud cuttings are taken, and especially that cuttings from stoolbed shoots root much more readily than from shoots of newly bedded plants. This holds for all the three apple rootstocks studied—M.V in 1954, 3430 and 3436 in 1956—and also for *Malus robusta* No. 5 (Nelson, 1955). Nelson also included cuttings from much older trees but these, though rather better than the two-year plants, were still greatly inferior to those from the stoolbed. The same superiority of stoolbed source has also been observed in relation to the rooting performance of hardwood stem cuttings (Garner and Hatcher, 1955).

As regards seasonal temperature during the period of growth of the source shoots, 1954 showed a further decline over the two earlier years, and a parallel seasonal trend in rooting is distinctly discernible (Table III). The rooting values given relate to leaf-bud cuttings of M.V taken at similar times in the different years and from comparable positions on the source shoots. The varieties in Trial II were other than M.V and it is not possible to compare directly the seasonal effect ; in fact, 1956 was another relatively cool year, and this probably contributed to the sparse rooting of cuttings from bedded plants.

TABLE III.

Relationship between air temperature (expressed as accumulated day-degrees above 42° F.) during growth of the source shoots and rooting of leaf-bud cuttings of M.V apple in a closed propagation frame.

Season	Accumulated day-degrees above 42° F.				Percentage rooting	
	April	May	June	April–June	Stool plants	Bedded plants
1952	8·9	14·1	17·1	13·4	72·1	—
1953	5·3	13·5	15·9	11·6	—	19·2
1954	4·7	11·8	12·5	9·7	33·3	2·5

In mist, cuttings remain in excellent health for a long time, this environment benefiting particularly those from bedded plants which root so slowly. Indeed, with more time such cuttings would have done even better, for all were in good condition when finally examined, with rooting still continuing. In the closed frame, on the other hand, all cuttings which failed to root within four or five weeks died, so that this environment is effective only for cuttings which root quickly, as did those from stoolbed shoots. Likewise, the intermittent mist method is particularly valuable with a rootstock which roots with some difficulty, as shown by the greater improvement in

3436 compared with 3430. It is timely here to recall that in the closed frame the accelerative influence of growth substance is essential, and to enquire whether the more leisurely reaction possible under mist would enable rooting to succeed without such stimulative treatment.

The results of these experiments show that the speed and degree of rooting of the leaf-bud cutting may be linked with some vigour characteristic of the source shoot. Thus the vigorous 3430 rooted more readily than 3436, a rootstock of only medium vigour. Also, within the same clone, the shoots from the stoolbed, which are supported by a well-established root system, are more vigorous than those from bedded plants whose roots are still establishing ; and the former have likewise proved greatly superior as a source. To get the full effect, the stoolbed must be earthed up at the base as the shoots grow. Another point worthy of note is that the balance of growth in a stoolbed, where a fresh shoot system develops each year, is much more disturbed by its pruning treatment than it is in a plant or tree. The general concept may similarly be applied to the observed seasonal effect, good rooting being associated with higher temperature during the growth of the source shoot.

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The authors acknowledge the guidance and encouragement of Dr. W. S. Rogers in the course of these studies. The first author expresses his appreciation of the opportunity to spend a year at East Malling which was given by Balwant Rajput College and Agra University and by the Government of India.

SUMMARY.

In experiments with three apple rootstock varieties the source of leaf-bud cuttings markedly influenced their rooting, speed and degree of rooting being linked with vigour of growth of the source shoot. This relationship held whether such vigour was inherent in the rootstock, induced by culture, or encouraged by favourable seasonal conditions.

Success with a closed propagation frame was dependent on rapid rooting. Under intermittent mist in the open, with partial shade, the speed of rooting was not limiting and this environment was much the more favourable and was particularly suited to slower rooting cuttings.

REFERENCES.

Garner, R. J., and *Hatcher, E. S. J.* (1955). The influence of source and growth substance on the behaviour of apple and plum cuttings. J. hort. Sci., **30,** 116–28.

———, ———, and *Nicoll, Catherine P.* (1954). Experiments with apple leaf-bud cuttings. Rep. E. Malling Res. Sta. for 1953, 145–9.

Nelson, S. H. (1955). Propagation by leaf-bud cuttings. Amer. Nurserym. **102,** 11 and 41.

Singh, S. M., Rogers, W. S., and *Slater, C. H. W.* (1957). Mist propagation frames for leafy cuttings. Rep. E. Malling Res. Sta. for 1956, 54–9.

Tydeman, H. M. (1943). Further studies in new varieties of apple rootstocks. J. Pomol., **20,** 116–26.

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SOME EXPERIMENTS TO INVESTIGATE THE CONTROL OF APPLE SAWFLY, *HOPLOCAMPA TESTUDINEA* (KLUG), BY CONCENTRATE SPRAYS

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It has become the practice of fruit growers to combine insecticides and fungicides in a single spray whenever this is possible. Hence, when Moore (1957) demonstrated that finely atomized, undiluted lime-sulphur could give control of Apple Scab and Apple Mildew comparable to that obtained by normal hydraulic sprays of dilute concentrations of the same material, it became clear that commercial application of this new idea would be dependent not only on the manufacture of suitable machinery for orchard use but also on the successful development of similar methods for pest control.

Moore (1954) reached the conclusion that three gallons per acre was the optimum quantity of undiluted lime-sulphur required for safe and effective cover of small trees, five to seven feet in height, when planted at three hundred to the acre. Furthermore, there was little difference in disease control when 50 per cent. lime-sulphur, used at a moderate increase in volume per acre, was compared with the undiluted liquid ; lower concentrations were less efficient and liable to cause more russeting of the fruit.

The terms of reference for the investigations were to determine whether insect pests could be controlled satisfactorily by applying an insecticide in admixture with the lime-sulphur used for scab and mildew control. Apple Sawfly was chosen as the test insect, partly because its fruit-infesting habits suggested that it might prove more difficult to control than species living exposed on the foliage, and also because it was known to occur regularly in sufficient numbers on the trees available for this work.

Materials and methods.

Layout of trials.

The trials were carried out on mature trees of Worcester Pearmain on M.IX rootstock, from five to seven feet in height, and planted at three hundred to the acre. Single tree plots were used with fivefold replication, guards being omitted, since with small trees contamination by spray drift could be effectively prevented by the use of a screen and as no movement of Apple Sawfly larvae takes place from tree to tree. Because of the active habits of adult sawflies and of the proximity of other apple trees there was little risk of any residual effect arising from a single year's treatment; the same trees were thus used throughout the investigation although the treatments were randomized annually.

Chemicals.

Several insecticides, known to be effective as dilute sprays against Apple Sawfly (Kirby and Gambrill, 1953) were available for study by this new method of application, the additional requirement of compatibility with concentrated lime-sulphur

Table I.

Treatments applied and the concentrations and dosages per acre of insecticides in the trials.

Treatment	Gallons of spray per acre	Lime-sulphur %	Insecticide %	Insecticide lb./ac.	Treatment	Gallons of spray per acre	Lime-sulphur %	Insecticide %	Insecticide lb./ac.
1954					*1956*				
Aldrin	3	50	4·5	1·35	γ-BHC	3	96·0	0·42	0·125
,,	450	1·0	0·05	2·25	,,	3	92·0	0·84	0·25
Nicotine	3	50	0·5	0·15	,,	3	87·5	1·25	0·375
,,	3	50	1·5	0·45	,,	600	1·0	0·0065	0·39
,,	3	50	4·5	1·35	,,	3	—	0·42	0·125
,,	300	1·0	0·05	1·5	,,	3	—	0·84	0·25
Lime-sulphur	3	50	—	—	,,	3	—	1·25	0·375
					Endrin	3	96·0	0·84	0·25
,,	300	1·0	—	—	,,	3	94·0	1·25	0·375
1955					,,	3	92·0	1·68	0·5
γ-BHC	3	98·5	0·13	0·04	,,	3	—	0·84	0·25
,,	3	96·0	0·4	0·12	,,	3	—	1·25	0·375
,,	250	1·0	0·0065	0·163	,,	3	—	1·68	0·5
Aldrin	3	99·5	0·17	0·05	Nicotine	3	—	4·5	1·35
,,	3	98·5	0·5	0·15	Lime-sulphur	3	100	—	—
,,	3	95·0	1·5	0·45					
Nicotine	3	95·5	4·5	1·35					
Lime-sulphur	3	100	—	—					

being recognized. Particulars of the treatments applied are listed in Table I. Of these, nicotine, being liquid, water-soluble and chemically stable in admixture with concentrated lime-sulphur, presented no problem in formulation but was open to objection on grounds of increased mammalian toxicity risk at the projected higher concentrations. Aldrin, selected from the less poisonous alternatives to nicotine as being the insecticide least likely to undergo decomposition by lime-sulphur, was replaced in 1956 by endrin which, in the meantime, had been developed commercially as the representative of this family of chlorinated insecticides for use on fruit. It was also decided, in 1955, to include γ-BHC although there was some doubt of its chemical stability in concentrated lime-sulphur. However, the promising results obtained with this mixture in the field, and laboratory tests which revealed little or no dehydrochlorination of emulsified γ-BHC by lime-sulphur, justified more intensive study of this material. Therefore, in 1956, γ-BHC and endrin were applied at similar dosage rates, mixed with lime-sulphur and with water, to find out whether the former was likely to reduce the toxicity of the insecticide. Nicotine was applied only with water.

After the exploratory work of 1954 and 1955 it was clear that effective control by concentrate application needed approximately the same amount of insecticide per acre as would be applied hydraulically. Dosages in 1956 were, therefore, chosen to fall on either side of the values calculated from the conventional hydraulic rates of 0·0065 per cent. γ-BHC and 0·0125 per cent. endrin when applied at 250 gallons per acre (i.e., 0·16 lb./ac. γ-BHC and 0·31 lb./ac. endrin).

In addition to the concentrate applications, treatments by conventional hydraulic machinery at normal concentrations were included for each chemical in 1954. This was to ensure that, should the application of concentrate prove a failure, further

information would be available for judging whether lack of control could be attributed to inefficiency of the insecticide or to other causes such as bad timing. In 1955 and 1956 a standard hydraulic treatment of 0·0065 per cent. γ-BHC, which had previously given consistently good results (Dicker and Briggs, 1953 ; Barlow, Dicker and Briggs, 1955) was included for similar reasons.

The formulations used were as follows :

Nicotine—a commercial grade containing 96–98 per cent. alkaloid. The hydraulic sprays in 1954 also contained 0·025 per cent. non-ionic surfactant.

Aldrin. In 1954 the hydraulic spray was prepared by adding to the spray tank an acetone solution of the insecticide and a non-ionic surfactant, the final concentrations being 0·05 per cent. aldrin, 0·025 per cent. surfactant and 2·0 per cent. acetone. The dispersion for concentrate application was obtained by mixing equal volumes of lime-sulphur and an emulsion concentrate containing 9 per cent. aldrin. In 1955 a commercial miscible formulation containing 30 per cent. aldrin was used.

γ-BHC—a commercial miscible formulation containing 10 per cent. γ-BHC. The hydraulic sprays in 1955 and 1956 also contained 0·025 per cent. sodium di-octyl sulphosuccinate as surfactant.

Endrin—a commercial miscible formulation containing 20 per cent. endrin.

Spraying equipment.

The concentrates were applied by a spray-gun of the type normally used for paint spraying and adapted by Moore (1957) for the application of lime-sulphur. The spray fluids were gravity-fed, the air for atomization being supplied by a mobile, petrol-driven compressor working at a pressure of 30–35 lb./sq. in. This instrument had previously been calibrated for fungicidal trials, when drop sizes were estimated from sprays deposited on prepared microscope slides (3 in. × 1 in.) at a distance of four feet from the gun. One hundred per cent. lime-sulphur, 50 per cent. lime-sulphur and water gave respectively drops ranging up to 80, 120 and 140μ with a mass median diameter of 33, 45 and 63μ, the term drop referring to the liquid particle and not the resulting stain. From further data obtained during calibration tests it was also clear that the drop spectra of the combined sprays used in the current experiments, in which the amount of insecticide seldom exceeded 5 per cent. of the total volume, would approach very closely to that quoted for lime-sulphur or water alone.

The combination of a narrow cone of spray, as produced by the gun, and the short carry of the particles meant that each branch had to be sprayed systematically from a range of a few feet. Under less favourable weather conditions the distance had to be reduced to approximately 18 inches. Uniformity of application was maintained by placing a measured volume of spray fluid in the reservoir and exhausting this before repeating the process at the next tree. Three gallons of spray applied to 300 trees per acre corresponds to a dosage of 45 ml. per tree ; as far as possible this rate was used, although the quantity was varied for occasional trees which were much larger or smaller than the average.

The dilute sprays were applied by hand lance at a pressure of approximately 250 lb./sq. in. from normal hydraulic spraying equipment. In 1954 and 1955 the rate of application was usually 250–300 gallons per acre ; in 1956 it was 600 gallons per acre.

Date of application.

Throughout this investigation it was assumed that the optimum time of application for a concentrate spray would be the same as when hydraulic machinery is used. Application by the latter has been studied by Dicker and Briggs (1953) who showed that, for both parathion and γ-BHC, effective control could be obtained by spraying at any time during the ten-day period immediately following 80 per cent. petal fall.

In 1954 spraying commenced on 21st May and was continued and completed on 24th May. Light showers occurred twice on the first day but only at times when all spray deposits were dry ; further light rain fell on 25th May and 0·5 in. was recorded on 28th May. The blossom had reached the 80 per cent. petal fall stage by 19th May, petal fall being virtually complete when spraying took place.

In 1955 all sprays were applied on 25th May. At least 18 hours elapsed before any rain fell, then 1·0 in. was recorded during the next two days. Petal fall reached the 80 per cent. stage on 22nd May and was complete by the time of spraying.

In 1956 sprays were applied at full petal fall on 22nd May, three days after the 80 per cent. stage ; only slight rain fell during the following six days.

Assessment of results.

Infestations of Apple Sawfly, in the trial conducted in 1954, were assessed by collecting and grading for damage, at twice-weekly intervals, all dropped fruits from beneath the experimental trees. Collections began in early June, when fruitlets had reached a diameter of 5 mm., and continued until all infested apples had fallen, approximately six weeks later ; the total fruits remaining on each tree were then counted.

In 1955 and 1956 an entirely different method of assessment was employed, viz. by making a single inspection of apples on the trees about the time larvae were entering the final instar. Samples from each of four sides of each tree, comprising 50 apples per sample in 1955, and 35 apples in 1956 when the crop was lighter, were inspected and those in which a larva had burrowed deeply into the flesh were classified as infested. Apples having only a superficial ribbon scar were omitted from the infested category as previous experience had shown that larvae occasionally burrowed a short distance beneath the epidermis before being killed by the insecticide.

Biological notes.

Previous studies (Dicker, 1953) had shown that adult sawflies are normally present on the trees throughout the blossom period, oviposition taking place in open blossoms by insertion of the egg into the receptacle just beneath the base of the stamens. Biological observations were not made in 1954 ; in the two following years development of both egg and larva was followed, from the date of spraying until the late larval instars, by inspecting all the fruitlets in a sample of 50 trusses taken at two- or three-day intervals from nearby trees of the same variety which had received no insecticide at petal fall.

Kirby and McKinlay (1953) described five stages which could be easily recognized between the time of oviposition and hatching. For the purpose of the present study these were reduced to :

(i) *swelling*, which included eggs in all stages of development prior to pigmentation appearing in the eyes of the embryo ;
(ii) *brown eye*, when brown pigment was visible in the eyes of the embryo ;
(iii) *brown mandible*, when the mandibles also developed brown pigmentation.

As the rupture of the epidermis overlying the egg on the inside of the calyx cup, a stage used by the above authors, appeared to be more closely associated with the depth at which the egg was deposited in the plant tissue than with a developmental stage, this category was omitted. Exposure of the egg may be important, in relation to time of application, for a chemical acting as an ovicide, but Kirby and McKinlay showed (*loc. cit.*) that embryonic development continued normally after the application of nicotine, aldrin, γ-BHC and several other materials, although the larva died after hatching, possibly by the chemical acting as a stomach or a contact poison. A similar mode of action would also be expected from endrin, although this material was not investigated by these workers.

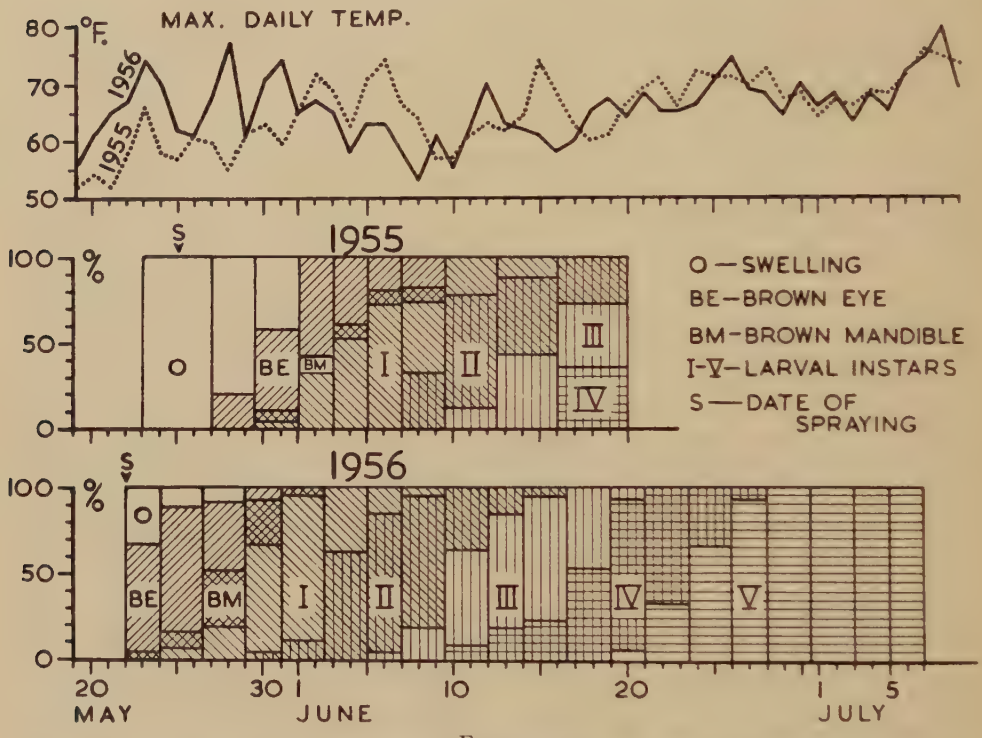

Fig. 1.

Development of the embryo and larva of the Apple Sawfly under field conditions in 1955 and 1956 and, above, the maximum daily screen temperature.

The data on embryonic and larval development, as obtained from field sampling in 1955 and 1956, are illustrated in Fig. 1, where the number of each stage present on any one occasion is shown as a percentage of the total of all stages present on that particular date. The main point of immediate interest shown in Fig. 1 is that, at the time of spraying, the eggs had reached a more advanced stage of development in 1956 than in 1955. This may have been due to oviposition taking place earlier in the blossom period in 1956, to the higher temperatures prevailing in that year, or to a combination of both factors.

Results of spraying.

Tables II and III show the percentages of infested fruit as recorded, and also after transformation to angles of equal information, both as arithmetic means. The significant differences quoted were derived from statistical analysis of these latter data.

Table II shows that, in 1954, there was no significant difference in sawfly infestation following the application of lime-sulphur alone, either at 1 per cent. by hydraulic machinery or at 50 per cent. with the paint gun ; nor is there any reason to suppose that the use of 100 per cent. lime-sulphur in 1955 and 1956 had any effect. It is thus reasonable to assume that any differences in infestation which have been observed in these trials are due to the insecticides employed.

Table II.

Results of spraying trials in 1954 and 1955.

Treatment	Lb./ac.	Gall./ac.	1954		1955	
			Per cent. infested fruit	Transformed value*	Per cent. infested fruit	Transformed value*
γ-BHC	0·04	3	—	—	12·2	20·1
,,	0·12	3	—	—	6·1	14·0
,,	0·163	250	—	—	0·5	3·9
Aldrin	0·05	3	—	—	32·3	34·5
,,	0·15	3	—	—	27·9	31·6
,,	0·45	3	—	—	12·7	19·9
,,	1·35	3	4·3	11·9	—	—
,,	2·25	450	1·0	5·7	—	—
Nicotine	0·15	3	43·7	41·3	—	—
,,	0·45	3	36·8	37·3	—	—
,,	1·35	3	37·0	37·1	17·1	24·3
,,	1·50	300	15·0	22·7	—	—
1% lime-sulphur		300	40·0	39·2	—	—
50% ,,		3	46·7	43·1	—	—
100% ,,		3	—	—	24·5	29·4

* Data transformed to angles of equal information ; sig. diff. (P = 0·05), 5·77 for 1954, 6·04 for 1955.

Compatibility of the insecticides with lime-sulphur.

Possible loss of insecticidal activity of γ-BHC, as a result of chemical dehydrochlorination by undiluted lime-sulphur, initially militated against the selection of this insecticide for field study. However, studies in the laboratory showed that the extent to which dehydrochlorination occurred was negligible when the insecticide was in solution in an organic solvent, such as benzene, which was then emulsified into undiluted lime-sulphur, conditions which would represent the result obtained by a fruit-grower when mixing a miscible formulation of γ-BHC with lime-sulphur. There remained, however, the possibility that some other form of incompatibility could exist which might inhibit the insecticidal action of γ-BHC and, indeed, of endrin. Accordingly, in 1956, treatments were included in which these insecticides were applied, at the same dosages per acre, in a medium other than lime-sulphur. As an inert medium

TABLE III.

Results of spraying trial, 1956.

Treatment	Lb./ac.	Gall./ac.	100% lime-sulphur		Water	
			Per cent. infested fruit	Transformed value*	Per cent. infested fruit	Transformed value*
γ-BHC	0·125	3	3·7	9·3	18·3	25·0
,,	0·25	3	1·6	6·8	7·1	13·3
,,	0·375	3	1·3	5·2	3·9	9·4
,,	0·39	600	—	—	0·0†	2·7†
Endrin	0·25	3	7·4	14·4	9·6	16·6
,,	0·375	3	2·0	7·4	8·4	14·3
,,	0·50	3	2·4	6·6	2·4	7·9
Nicotine	1·35	3	—	—	33·1	34·9
100% lime-sulphur		3	47·5	43·5	—	—

* Data transformed to angles of equal information ; sig. diff. (P = 0·05), 8·18.
† Spray also contained 1 per cent. lime-sulphur.

possessing the physical properties of lime-sulphur could not be devised, the same quantities of the miscible formulations were applied with water as the diluent. The results obtained (Table III) show that any misgivings that the physical or chemical properties of lime-sulphur itself, or of the deposit therefrom, might reduce the effectiveness of the insecticides were unfounded. On the contrary, treatments based on the fungicide were more effective than those based on water. These differences may well reflect higher initial deposits of insecticide from the finer drop spectra given by lime-sulphur and/or improved persistence of the insecticide in the presence of the firmly adherent fungicide deposit.

Effect of chemicals in combination with lime-sulphur.

γ-BHC. Applied in 1955 as a concentrate at 0·04 lb./ac. with 100 per cent. lime-sulphur, γ-BHC reduced the sawfly infestation by about 50 per cent. ; an increase in dosage to 0·12 lb./ac. gave a further significant increase in control, but both these treatments were significantly less effective than the hydraulic application of the same insecticide. Under the conditions prevailing in 1956 γ-BHC, applied at 0·125, 0·25 and 0·375 lb./ac. with 100 per cent. lime-sulphur, gave results which did not differ significantly, either among themselves or from the complete control obtained with the hydraulic application.

Consideration of both years' results shows that, when γ-BHC was applied as a concentrate with 100 per cent. lime-sulphur, reductions in infestation were observed which reflected the dosages of insecticide used up to the rate of 0·12 lb./ac. At this level, control was satisfactory in 1956 but not in 1955. That this is a marginal dose, which is satisfactory only under optimum conditions, is further indicated by the results obtained with γ-BHC and water in 1956. In combination with water, in which the insecticide appears to be less efficient, γ-BHC at 0·12 lb./ac. gave results significantly inferior to those with the two higher dosage rates.

Turning now to the hydraulic sprays : 0·0065 per cent. γ-BHC with 1 per cent. lime-sulphur gave virtually complete control both in 1955 and 1956. The dosages per acre, corresponding to the quantity of spray used in these two years, were 0·16 lb. from 250 gallons in 1955 and 0·39 lb. from 600 gallons in 1956. These results suggest that 250 gallons per acre (0·16 lb. γ-BHC) was adequate for control of Apple Sawfly under the conditions described and that an excessive quantity of spray was used in 1956. Confirmation of this conclusion is available from the results of Dicker and Briggs (1953) who also obtained excellent control on trees of similar size with 250 gallons per acre. It therefore appears that for γ-BHC, under the conditions prevailing in these experiments, a concentrate spray applied at a rate between 0·12 and 0·25 lb./ac. gave control of the same order as that obtained with 0·16 lb./ac. applied hydraulically.

Aldrin. Applied in 1954 as a concentrate at 1·35 lb./ac. with 50 per cent. lime-sulphur, aldrin reduced the infestation by an amount which was just significantly less than that obtained by hydraulic spraying with the same insecticide. The dosage rates chosen for use with 100 per cent. lime-sulphur in 1955 were on the low side, two of them failing to achieve any control, but the infestation was halved by applying 0·45 lb./ac. This result, taken in conjunction with the 1954 figures, again indicates a strong positive correlation between dosage rate and kill, and suggests that the optimum dosage for a concentrate spray under the prevailing conditions would have been approximately 1·5 lb. aldrin per acre. Also, if the effective rate of application for the hydraulic spray is considered to be 250 gallons per acre (i.e., 1·25 lb./acre) as it was for γ-BHC, then it again becomes apparent that about the same amount of aldrin per acre will be required irrespective of the method of application.

Endrin. The results obtained with this material (Table III) show that, when applied with 100 per cent. lime-sulphur, all three dosages gave levels of control which did not differ significantly. However, the reduction given by the lowest rate (0·25 lb./ac.) is almost significantly different from that given by the highest (0·50 lb./ac.). In addition, when this insecticide was applied with water, the performance at 0·25 lb./ac. was significantly inferior to that at 0·5 lb./ac., and a noticeable drop in control was also observed with 0·375 lb./ac. These results suggest that 0·25 lb./ac. is a marginal dosage.

No hydraulic application was made with this material, but according to the manufacturer's recommendation an application at 250 gallons per acre would need 0·31 lb., which is slightly above the lowest, and doubtfully effective, dosage rate used in the concentrate experiment. Thus the results again indicate that a similar dosage rate is necessary for satisfactory control, whether the material is applied as a concentrate or as a conventional high volume spray.

Nicotine. Nicotine gave poor results. The best performance during the three years was given in 1954 by the hydraulic application of 0·05 per cent. in 1 per cent. lime-sulphur, but even here the reduction in infestation was significantly inferior to that given by aldrin by either method of application. As a concentrate in 1954, 0·15 lb./ac. had no noticeable effect whereas 0·45 and 1·35 lb./ac. both reduced the infestation to a level which was just, but only just, significantly different from that in the 50 per cent. lime-sulphur treatment. At 1·35 lb./ac. the reduction in infestation was not significant in 1955 and only barely so in 1956. Thus, when applied as a concentrate, nicotine can be said to have failed completely. The highest rate used (1·35 lb./ac.) slightly exceeds the amount resulting from a hydraulic application of 0·05

per cent. nicotine at 250 gallons per acre (1·25 lb./ac.) which, in discussing previous insecticides, has been taken as a standard rate ; nevertheless, at this level only a slight reduction in infestation was achieved irrespective of whether the diluent was 50 per cent. lime-sulphur (1954), 100 per cent. lime-sulphur (1955), or water (1956).

For sprays applied at 80 per cent. petal fall, delayed larval development in cool seasons has been postulated in explanation of the poor performance of nicotine applied hydraulically for the control of Apple Sawfly (Kirby and McKinlay, 1953) ; it may be assumed that this factor is also important for the efficiency of concentrates. Detailed biological observations were not made in 1954, but a study of the meteorological records gives no grounds for supposing that embryo development did not proceed normally and was not completed within the period of time considered to be critical by the workers just cited. In 1955 and 1956, as Fig. 1 shows, timing and post-spraying conditions appear also to have met the requirements for efficient action, as at present understood. Nevertheless, the sprays proved ineffective. The results obtained with aldrin, γ-BHC and endrin, which have already been discussed, indicate in each case a certain minimum dosage of insecticide per acre for effective control. The results obtained with nicotine over the three years suggest that either a different mode of action is involved when the insecticide is applied as a concentrate or that a dosage per acre higher than those used is required. The highest level of control was given by the highest dosage per acre, viz., 1·5 lb./ac. from 300 gallons of 0·05 per cent. nicotine applied hydraulically in 1954. It may be, therefore, that the rate (1·25 lb./ac.) which results from normal hydraulic spraying is itself a borderline dosage and that an inadequate insecticide threshold may be involved in the occasional failure of nicotine to control sawfly.

Phytotoxicity.

Although no foliage injury of economic importance was observed, there were slight traces of marginal scorch on young leaves of the extension growth following some treatments with lime-sulphur. In general it was greatest when 1 per cent. lime-sulphur, either alone or in combination with an insecticide, was applied by hydraulic machinery, but none was recorded from trees receiving only concentrated lime-sulphur or insecticides diluted with water. The intensity of leaf scorch with nicotine in 1954 and with γ-BHC and endrin in 1956, in combination with concentrated lime-sulphur, appeared to be roughly proportional to the quantity of insecticide, there being no injury at the lowest rates but increasing amounts at the intermediate and highest rates of application.

Effect on yield.

The tree-to-tree variation was so great that it was impossible, with only fivefold replication, to obtain any correlation between the intensity of sawfly infestation and the crop at harvest time. The only consistent feature was that in each year the control trees carried the lightest crop.

DISCUSSION.

Since the experiments described in this paper were conducted on small trees and with techniques designed especially for intensive trials, it cannot be assumed that the dosage rates found to be effective under the experimental conditions will give equally

satisfactory results when applied by full scale machinery to commercial orchards. For example, the deposit obtained by directing the spray at each branch from a paint gun is probably both greater and more uniform than could be attained from completely automatic application with standard farm machinery when the spray is being emitted continuously irrespective of whether a tree or a gap between trees is the target area.

Nevertheless, certain general principles have been established, the main one being that the amount of insecticide per acre required for control of the Apple Sawfly is of the same order irrespective of whether it is applied as a concentrate or as a dilute spray. This is clearly indicated by the results obtained with the chlorinated hydrocarbons, γ-BHC, aldrin and endrin. On the other hand, nicotine failed to give control when used at a rate equivalent to that normally applied by hydraulic machinery, but the past record of this chemical in a hydraulic spray is one of variable results. A conclusion that can be drawn from the current investigation is that the failure of nicotine may be due to an inadequate dosage rate when the application is made at the conventional time. Such an idea does not invalidate the theory put forward by Kirby and McKinlay (1953) that insufficient insecticide persists to maintain a toxic residue at the time of hatching ; on the contrary, it may equally well explain why a sub-lethal dose is present at the critical period.

The 1956 results showed clearly that the toxicity of γ-BHC and endrin was not impaired when these insecticides were applied in admixture with concentrated lime-sulphur. It is true that the combination of insecticide and lime-sulphur remained in the liquid state for only a short time, not exceeding a period of 10–15 minutes, but laboratory tests clearly showed that dehydrochlorination of γ-BHC occurred at such a slow rate that no loss of toxicity from this cause would be expected under normal commercial conditions. The comparison of lime-sulphur and water as diluent did, however, indicate that efficiency of the insecticide may vary in different liquid media, although whether this is due to the physical properties of the medium or to other causes has not been ascertained.

SUMMARY.

Small-scale field trials have been carried out during three seasons to determine whether Apple Sawfly, *Hoplocampa testudinea* (Klug), can be satisfactorily controlled by applying small volumes of concentrated dispersions of insecticides in strong lime-sulphur. The insecticides studied were nicotine and the three chlorinated hydrocarbons, γ-BHC, aldrin and endrin. Apart from nicotine, the sprays were prepared by mixing commercially available miscible formulations of the insecticides with concentrated lime-sulphur. They were applied by paint-gun at the rate of three gallons per acre to apple trees, five to seven feet in height and planted at three hundred to the acre. It was found that for each insecticide studied there exists a dosage per acre below which consistent control is doubtful.

In the case of γ-BHC, aldrin and endrin these amounts agree closely with those resulting from conventional concentrations applied hydraulically at 250 gallons per acre, viz., 0·16 lb./ac. γ-BHC, 1·25 lb./ac. aldrin and 0·31 lb./ac. endrin. Nicotine, applied as a concentrate at a rate equivalent to 250 gallons per acre of 0·05 per cent. solution (i.e. 1·25 lb./ac.), failed to control sawfly and it is suggested that this may have resulted from the use of a sub-lethal dosage. By analogy with the results

obtained from the other insecticides this result further indicates that occasional failures of nicotine, when applied hydraulically, may also be due to too low a concentration of insecticide in the spray.

Slight and consistently higher levels of control were obtained when γ-BHC or endrin was applied in admixture with concentrated lime-sulphur, as compared with equivalent dosage rates applied in water. This result demonstrates that no serious incompatibility exists between these insecticides and lime-sulphur.

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REFERENCES.

Barlow, H. W. B., Dicker, G. H. L., and *Briggs, J. B.* (1955). Studies on control of Apple Sawfly, *Hoplocampa testudinea* (Klug). II. Effect of sprays on fruit drop and yield. Rep. E. Malling Res. Sta. for 1954, 107–14.

Dicker, G. H. L. (1953). Some notes on the biology of the Apple Sawfly, *Hoplocampa testudinea* (Klug). J. hort. Sci., **28,** 238–45.

———, and *Briggs, J. B.* (1953). Studies on control of Apple Sawfly, *Hoplocampa testudinea* (Klug). I. Effect of time of spraying. Rep. E. Malling Res. Sta. for 1952, 151–5.

Kirby, A. H. M., and *Gambrill, R. G.* (1953). The use of some newer insecticides for the control of Apple Sawfly, *Hoplocampa testudinea* (Klug). J. hort. Sci., **28,** 163–9.

———, and *McKinlay, K. S.* (1953). Some factors affecting the control of Apple Sawfly, *Hoplocampa testudinea* (Klug), by nicotine and other chemicals. J. hort. Sci., **28,** 170–6.

Moore, M. H. (1954). Is concentrate spraying with lime-sulphur a practical proposition ? Rep. E. Malling Res. Sta. for 1953, 210–12.

——— (1957). Concentrate spraying of apple trees. I. Fungicidal efficiency of lime-sulphur. Ann. appl. Biol., **45,** 11–18.

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FURTHER INVESTIGATIONS OF FLOWER-BUD DEVELOPMENT IN THE GENUS *RUBUS*

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STUDIES have been made in Scotland on the initiation and development of flowers of the red raspberry (Mathers, 1952 ; Wood and Robertson, 1957) and here and elsewhere in Britain on flower initiation in strawberries (Guttridge, 1952 ; Robertson and Wood, 1954 ; Robertson, 1955), but there has apparently been no similar work in this country with blackberries and other species related to the red raspberry. Waldo (1933), in America, made studies of this kind on blackberries, red and black raspberries, purple-cane hybrid raspberries and certain other hybrid berries, comparing their behaviour in Maryland and Oregon. Many of these forms of *Rubus*, if not native here, are now of interest to British plant breeders, and a knowledge of their flower development is desirable.

MATERIAL AND METHODS.

Examinations were made of buds of the following species and hybrids, all (except the local blackberry) growing in the *Rubus* collection at Mylnefield :

Red raspberry (*R. idaeus* L.), var. Lloyd George ;
Black raspberry (*R. occidentalis* L.), var. Cumberland ;
Purple-cane hybrid raspberry (*R. occidentalis* × *R. idaeus*) ;
Loganberry (East Malling clone) ;
Blackberry, vars. Himalayan Giant and Ashton Cross and a local wild form.

First-year canes of the loganberry and the blackberries were divided into tip, middle and basal zones of roughly equal length, which were sampled separately, but the raspberry buds were taken only from the upper halves of the canes. These canes were winter-tipped in late January at about 4¾ feet above ground level, a treatment that removed very little growth from Lloyd George but an appreciable amount from the black and hybrid raspberries. The loganberry and blackberry canes were also shortened moderately in January. Samples of three or four buds of each variety and cane region were dissected weekly from 28th August 1953 to 12th May 1954 and field records were afterwards made on flower emergence.

As in previous work, the degree of differentiation of the terminal flower was used as a measure of the development of each inflorescence, the following arbitrary stages being recognized :

1, growing point of axis flattened ;
2, perianth ring just visible ;
3, perianth initials distinct ;
4, anther rudiments just visible ;
5, anther rudiments distinct ;
6, carpels forming at base of torus ;

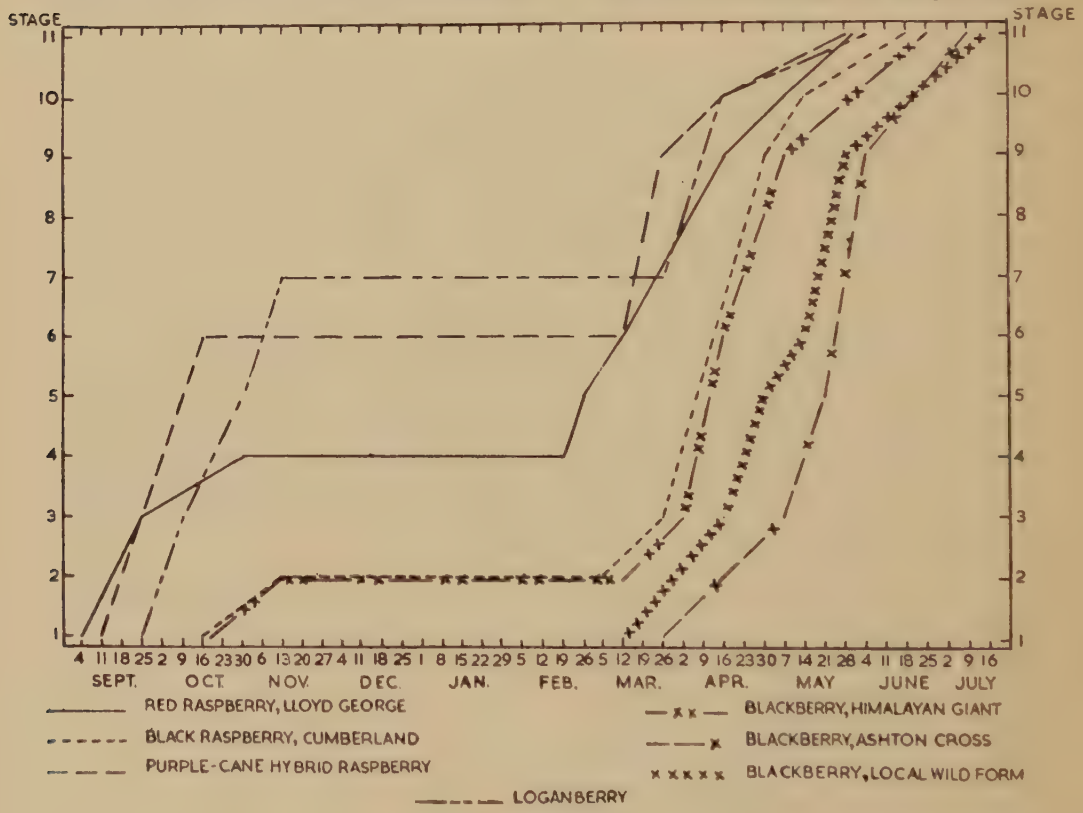
* Resigned September 1954.

7, carpels half-way up torus ;
8, carpels three-quarters covering torus ;
9, carpels covering torus ;
10, carpels elongated and anthers lobed ;
11, first flowers open.

In all these forms of *Rubus* the canes typically bear two distinct buds at each node, a large primary bud and, below it, a smaller secondary bud (Wood and Robertson, 1957). Most fruiting laterals are formed in spring by extension of the axes of primary buds, although in some varieties or under certain conditions both types of bud may produce laterals. Where primary laterals fail to develop or are damaged, secondary laterals frequently replace them. In addition, smaller buds (termed tertiary) in the scale axils of the primary and secondary buds may also on occasion give rise to fruiting laterals (termed tertiary laterals), usually of weak growth.

RESULTS.

The results of the dissections are described in detail below ; but in order first to provide a general picture, the development of primary inflorescences in the various fruits is illustrated comparatively in Fig. 1. The red raspberry, the purple-cane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SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUNE JULY
RED RASPBERRY, LLOYD GEORGE
BLACK RASPBERRY, CUMBERLAND
PURPLE-CANE HYBRID RASPBERRY
LOGANBERRY
BLACKBERRY, HIMALAYAN GIANT
BLACKBERRY, ASHTON CROSS
BLACKBERRY, LOCAL WILD FORM

FIG. 1.
Development of primary inflorescences.

hybrid and the loganberry all showed early flower initiation and considerable further development in autumn, whereas development in the black raspberry and blackberries occurred mainly in spring. In Ashton Cross and the local blackberry no flower initiation was seen until March, but in Himalayan Giant and the black raspberry stage 2 was reached before winter.

RED RASPBERRY (*R. idaeus* L.), VAR. LLOYD GEORGE.

This well-known raspberry, in which flower development had already been studied (see above), was included as a standard of comparison for the other fruits.

Main axes of primary buds were vegetative on 28th August, but two of six buds examined on 4th September contained inflorescences of six flowers at stages 3 and 1. The perianth was generally distinct by late September and first anther initials (stage 4) appeared during October. Most inflorescences remained at this stage until late February, except for the probable addition of some further anther initials. Carpels were generally not differentiated until March, although occasionally they were found earlier. By mid-April the anthers were enlarged and lobed, all the carpels had been formed and the oldest were elongating. The flower number increased from an average of five per inflorescence in September to 11 during winter and 12 in spring. Budburst stage was generally reached by 26th March and green-bud stage by early May. Flowering began by 1st June.

The secondary inflorescence was initiated at about the same time as the primary but developed more slowly. Flower primordia were recognizable in early September, showed sepal rudiments in early October but developed little further until mid-March, when anther initials appeared. Wide differences in development, ranging from stage 3 to stage 7, were seen among these inflorescences in late spring, and were independent of differences between the associated primary buds. The average flower number rose from three in September to five in winter and six in spring. Little frost injury of primary laterals occurred in 1954 and consequently few secondaries grew as replacements, but about 10 per cent. of the nodes carried both types of lateral.

Flower initiation in the oldest tertiary buds on primary-bud axes also began in September and development was often in advance of that on main axes of secondary buds. Stage 3 was generally completed by late October. Little further development occurred until early spring, except that occasionally, especially where the primary inflorescence itself was well advanced, anther formation began in autumn. The degree of development of individual tertiary buds in spring varied considerably. The few tertiary laterals that grew out were short and weak, with few flowers and were mainly near the tips of canes. Where, however, the primary bud had developed to form a branch cane in the previous year, sometimes one or more of its tertiary buds, as well as the secondary bud, produced well-developed fruiting laterals.

The two oldest tertiary buds on secondary-bud axes were examined from December onwards. Their inflorescences had an average of three flower initials but were only at stage 1 by mid-March, and no further development was observed beyond the formation of perianth rudiments. These buds were not seen to produce laterals.

BLACK RASPBERRY (*R. occidentalis* L.), VAR. CUMBERLAND.

Primary buds in September were small and compact, with extremely small, rounded growing points. Inflorescences were first seen on 16th October, eight weeks

later than in Lloyd George, and contained an average of three small flower initials at stage 1. During winter most inflorescences were at stage 2, with five initials, but several buds remained vegetative. Perianth formation in March was followed by the rapid development of anthers and carpels in April. Carpels began to lengthen in mid-May, when the average flower number was about nine. Bud-break stage was reached by 12th March, bud-burst by the end of that month and green-bud by mid-May. Flowering began in mid-June.

Flower initials were not found in secondary buds until 13th November and about half the buds examined during the winter were vegetative. The others contained small inflorescences of one to three initials at stage 1. Inflorescences up to stage 2, with two to six flowers, were found during April. Few strong secondary laterals were seen in the field and these occurred only where the primary lateral had failed or been damaged.

Most tertiary buds remained vegetative, but in March a few on primary buds showed one or two very small flower initials. No tertiary laterals were seen.

Purple-cane Hybrid Raspberry (*R. occidentalis* × *R. idaeus*).

The hybrid studied was a seedling (Malling 53/9) raised at East Malling Research Station by crossing Naples Blackcap with a red raspberry selection derived from the varieties Lloyd George, Pyne's Royal and Preussen.

Primary buds examined on 28th August and 4th September were vegetative, with apices larger and broader than those of Lloyd George. Two of three buds examined on 11th September contained inflorescences of two and three initials at stage 1. Further development was rapid, but varied considerably between individual buds ; perianth initials (stages 2 and 3) were seen on 25th September, but buds examined in early October showed inflorescences at stages 1–6. Anther and first carpel rudiments were generally present by late October, from which time until mid-March most buds remained at stage 6, a more advanced overwintering condition than shown by Lloyd George. The remaining carpel initials were formed during late March and carpels were lengthening by mid-April. The average flower number rose from five in autumn to 11 in winter and 13 in spring. Bud-break started in early March, green-bud was reached by the end of April and flowering began on 1st June.

As in the black raspberry, flower initiation in the secondary buds began slightly later than in the primaries. Inflorescences of two or three initials at stage 1 were seen in buds examined on 25th September, subsequent development being slow. Most inflorescences overwintered at stage 2–3, although a few anther rudiments were formed in late autumn or winter. Carpels were formed mainly in April. The average flower number was small, rising from three initials in autumn to five during winter and six in spring. Secondary buds remained dormant in spring except where primary laterals failed or became damaged, when strong secondary laterals with about 12 flowers were often produced.

Tertiary buds were not examined systematically but were noted both in primary and in secondary buds. The oldest seen in a primary bud in late March carried an inflorescence of six flowers at stage 4, whereas corresponding ones in secondary buds were very small, mostly with three flower initials at stages 1–3. The only tertiary laterals seen were a few weak ones at the bases of damaged primary laterals.

LOGANBERRY (EAST MALLING CLONE).

Middle zone.

Flower initials were first seen in mid-cane primary buds on 25th September, three weeks later than in Lloyd George raspberry. Subsequent development resembled that in purple-cane hybrid raspberry, with again a range of differentiation among buds of similar age. Those examined from mid-November to late March showed torus rudiments lengthened to typical loganberry shape and more or less covered by carpels. In April the anthers became lobed and the carpels began to elongate. Bud-break began in late February, bud-burst and green-bud stages were reached by 2nd April and 1st May respectively and flowering began on 3rd June. The inflorescences carried an average of 10 flowers.

Secondary inflorescences were generally initiated in late October, although a few were seen at the beginning of the month. During the winter they remained at stages 1–3, with an average of three flower initials, except where the primary bud was dead ; development of the secondary bud was then usually more advanced. By April the secondary inflorescences examined varied between stages 2 and 9. Most of the buds remained very small and few formed laterals except where the primary lateral had failed or been damaged.

In this and also in the tip and basal zones the tertiary buds seen were invariably small and vegetative ; examinations of them were discontinued before late spring. None was seen to form laterals.

Tip zone.

True tip buds were available only until the canes were shortened in January. By 23rd October no primary inflorescence initials had been found in this zone, and those seen between then and 13th November, some at stage 5 or 6, were close to the middle zone. Flower initiation in true tip buds apparently occurred considerably later than in the middle part of the cane. Spring differentiation in the uppermost buds that remained after tipping was similar to that in mid-cane buds, though possibly a few days later.

The uppermost available secondary buds remained vegetative throughout the winter except where the associated primary buds were dead, when small inflorescences of two to four flowers at stage 2 were found. Inflorescences of two to five flower initials were general by early March and were mainly at stages 1–4 during April, although one inflorescence had then reached stage 9. Secondary laterals grew out only where primary buds were missing or damaged.

Basal zone.

Most primary buds in this zone had formed branches in the previous summer. Flower initials were seen in some of the remainder on 2nd October, about a week later than in mid-cane buds, but others remained vegetative during the winter and still others died. The inflorescences that were formed overwintered mainly at stage 6 or 7, with an average of eight flower initials. Spring development and time of flowering were much the same as in mid-cane buds.

Secondary buds were very small and many remained vegetative, but some formed small inflorescences of two to four flowers and reached stage 1 or 2 by mid-March. Development was more advanced at nodes where primary buds were dead.

Blackberry, var. Himalayan Giant.

Middle zone.

Flower initiation in primary buds began about mid-October but development advanced little until after winter. From November to mid-March most inflorescences were at stage 1 or 2, with an average of three flowers. About one-third of the primary buds examined in that period had dead apices, but generally in such cases one or two of the oldest tertiary buds had enlarged. Differentiation in the normal buds was rapid after mid-March, inflorescence axes lengthening considerably as flower numbers increased. Below the first-formed flowers, groups of three to seven more initials were formed in the axils of leafy bracts, and the average number of flower initials per inflorescence increased from eight in March to as many as 40 in early May ; but many of the small initials remained undeveloped, the average number of flowers to emerge being only 28. Of these, 8 to 14 formed the terminal cluster and the rest were borne on three to five main branches. During May, small groups of flower initials could be seen in the axils of leaves on the upper half of each lateral, below the main inflorescence. These developed during the summer and flowered in September and October.

The perianth of the terminal flower was distinct by early April. Anthers were forming within a further week, first carpel rudiments were present by 16th April, and by 10th May six anther whorls had been formed and carpel rudiments covered the torus. This rapid development was in contrast with the much slower differentiation in Lloyd George raspberry. Another difference was that the petals of Himalayan Giant were large at an early stage and were curved over the young anthers, whereas in all the raspberries they remained very small until just before the flowers opened. Bud-break in Himalayan Giant began in early April and green-bud was reached by mid-May, but flowering did not start until 26th June, about four weeks later than in Lloyd George raspberry.

Secondary buds remained vegetative until mid-March, when small inflorescences of up to eight flowers were found. These developed slowly, reaching only stage 2 or 3 by early May ; but isolated records in 1953 (the previous year) indicated that many secondary inflorescences developed slowly during the summer and flowered in August. Secondary laterals were formed in the spring of 1954 only where primary buds had died or been damaged, but those that developed to replace dead primary buds were as strong and carried as many flowers as most primary laterals.

Tertiary buds were either vegetative or contained small inflorescence primordia very late in development.

Tip zone.

The apices of about half the tip-cane primary buds dissected during winter were dead. Of the rest, only a few showed floral apices. By April, however, flower initials were regularly found, and flower numbers per inflorescence increased from between three and eight in that month to an average of 28 in May. Development was much the same as in mid-cane primary buds.

Secondary buds, vegetative throughout the winter, developed in spring as in the mid-cane region. A few tertiary buds showed small, late-formed flower initials.

Basal zone.

Most primary buds remained vegetative during the winter, but a few showed floral apices and others were dead. Inflorescences were regularly found after early March, flower number and development again being much the same as in mid-cane buds.

Most secondary buds also remained vegetative during the winter, but inflorescences of one to four flower initials were seen in some during April. A few tertiary buds on primaries which were examined in May contained inflorescences at stage 1 or 2.

BLACKBERRY, VAR. ASHTON CROSS.

Middle zone.

Primary buds examined during the winter were vegetative ; about one-quarter had dead main apices, but carried one or two considerably enlarged tertiary buds. Flower initiation began in late March. The main inflorescence was similar in form to that of Himalayan Giant, with many small branches, each carrying three to seven flowers, subtended by leaves or leafy bracts. Flower numbers increased rapidly from about six in early April to 30–40 in mid-May. The average number to emerge in the field was 46, about 25 in the terminal cluster and the remainder on three to seven branches immediately below it. Most of the lower leaves of the laterals subtended small clusters of flowers which opened from August to October, flower initiation apparently continuing basipetally along the lateral from the end of March until about mid-June.

The perianth of the terminal flower was distinct by early May, anther initials were formed within the next fortnight, and carpel initials largely covered the torus by the end of the month. There were four or five rings of stamens and the anthers were lobed by late May. As in Himalayan Giant, the petals enlarged early and curved over the stamens. Bud-burst was reached by mid-April and green-bud by the first week of June. Flowering began on 12th July.

Secondary buds generally remained vegetative, but about one-eighth of those examined were dead ; a few developed two to six flower initials during April. Where the primary buds had formed branch canes in the previous season, or had died during the winter, secondary inflorescences were formed which were almost as large as the primaries. Very occasionally a primary and a secondary lateral were present together at the same node.

Tip and basal zones.

Of the primary buds examined in these zones, almost half the tip ones and about a tenth of those at the base were dead. Flower initials in live buds of both zones were first seen on 2nd April, subsequent development being similar to that in mid-cane buds. About 5 per cent. of the secondary buds examined were also dead. All others remained vegetative, except where the associated primary buds had died or formed branch canes.

BLACKBERRY, A LOCAL WILD FORM.

Middle zone.

The primary buds—to which the observations were confined—were apparently all vegetative throughout the winter, but about one-tenth had dead apices. Flower

initials were first seen in mid-March, two weeks earlier than in Ashton Cross. Inflorescence axes lengthened considerably in spring as the average number of flower initials, in terminal and branch clusters, rose rapidly from nine in early April to about 40 in mid-May, of which 27 were later seen to open.

The perianth was distinct by 16th April, first anther initials were seen in the following week, and carpel initials appeared in the second week of May. After bud-break in early April, growth was rapid ; green-bud was reached in early June and flowering began on 15th July. In general, flower development during spring was later than in Himalayan Giant but earlier than in Ashton Cross.

Tip and basal zones.

In both these zones the buds remained vegetative until late March, one to two weeks longer than in the mid-cane zone. Flower numbers were slightly lower than in mid-cane buds and dates of anther and carpel initiation slightly later, but flowering dates were practically uniform in all zones.

DISCUSSION.

The results described agree fairly well with those of Waldo (1933), who reported flower initiation in loganberry and some varieties of red raspberry in September and early October, in purple-cane hybrid and black raspberries in October (Maryland) and early November (Oregon), and in Himalayan Giant blackberry in January (Maryland) and February (Oregon). Brainerd blackberry, of which Himalayan Giant is a parent, initiated flowers in both regions during November. Thus there is agreement that loganberry and red raspberries initiate flowers fairly early in autumn, black raspberries somewhat later and blackberries mainly in spring, but the present results show a rather earlier flower development in purple-cane hybrid raspberry than was found by Waldo. This might be because different varieties were used.

The present study was confined to one season. Apart from ordinary seasonal variations in vigour and time of growth, it is known that in the red raspberry the relative importance of primary, secondary and tertiary buds as sources of fruiting laterals is influenced by climate (Wood and Robertson, 1957), a flexibility of behaviour that appears to exist in at least some of the other fruits used in this study.

The small differences noted between the basal, central and tip zones of loganberry and blackberry canes indicated that the central zone buds were earliest to begin flower initiation and formed slightly larger inflorescences than buds in the other zones.

SUMMARY.

1. Dissections in the autumn and winter of 1953–54 showed that flower initiation began in seven forms of *Rubus* at the following approximate times : red raspberry (*R. idaeus*) var. Lloyd George, early September ; black raspberry (*R. occidentalis*) var. Cumberland, mid-October ; purple-cane hybrid raspberry (*R. idaeus* × *R. occidentalis*, a seedling of known origin), early to mid-September ; loganberry (East Malling clone), mid- to late September ; blackberry var. Himalayan Giant, mid-October ; blackberry var. Ashton Cross, late March ; blackberry (a local wild form), mid-March. These times refer to the primary (main) buds at cane nodes.

Initiation generally began later in secondary buds and still later, if at all, in tertiary buds (small buds in the scale-axils of primary and secondary buds).

2. The development of primary inflorescences reached a fairly advanced stage in autumn in the loganberry and in the purple-cane hybrid and red raspberries, but occurred mainly in spring in the black raspberry and in blackberries.

REFERENCES.

Guttridge, C. G. (1952). Inflorescence initiation and aspects of the growth habit of the strawberry. Rep. Long Ashton Res. Sta. 1951, 42.

Mathers, B. A. (1952). A study of fruit-bud development in *Rubus idaeus*. J. hort. Sci., **27,** 266.

Robertson, M. (1955). Studies in the development of the strawberry. III. Flower-bud initiation and development in large-fruited perpetual ("remontant") strawberries. J. hort. Sci., **30,** 62.

———, and *Wood, C. A.* (1954). Studies in the development of the strawberry. I. Flower-bud initiation and development in early- and late-formed runners in 1951 and 1952. J. hort. Sci., **29,** 104.

Waldo, G. F. (1933). Fruit-bud formation in brambles. Proc. Amer. Soc. hort. Sci., **30,** 263.

Wood, C. A., and *Robertson, M.* (1957). Observations on the fruiting habit of the red raspberry (*Rubus idaeus* L.) and on an occurrence of cane "die-back" in Scotland. J. hort. Sci., **32,** 172.

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BOOK REVIEWS

LIBERTY HYDE BAILEY. By PHILIP DORF. (New York : Cornell University Press. London : Oxford University Press. 1956. Pp. 259. Price 28s.)

This " informal biography " is the first full-scale account of the life of L. H. Bailey to appear ; it will certainly not be the last.

To readers of this journal, L. H. Bailey is doubtless best known as a horticulturist and the author or editor of many works on horticulture. But he was much more. It could fairly be said that he was first of all a botanist ; he also published works on evolution and various philosophical subjects, and was even the author of some quantity of verse. (The present reviewer, who heard L. H. Bailey read in public his first effort in verse form, remembers too well the remark of a particularly good judge of poetry who also heard him—" whatever he is, he's *not* a poet ! ").

L. H. Bailey was by far the most inspiring teacher the reviewer has ever known. His books had much the same effect as his personality. In 1905, when two of his students had asked for a talk with him about their future, they had to wait until he had finished his interview with a " truck " grower from Long Island. It appeared that this gentleman had by chance come across L. H. Bailey's *Principles of Vegetable Growing*, and in a state of wild excitement had rushed off to Ithaca to interview the author. It was plain when he emerged from his interview that his excitement had by no means subsided ; he looked like a cartoon picture of an escapee from a mental hospital.

This book gives a very readable account of L. H. Bailey's origin in the backwoods of Michigan, and his rapid advancement till he succeeded Professor Roberts as Dean of the College of Agriculture at Cornell University. Having got the College well established as the New York State College of Agriculture, Bailey, then aged 55, insisted on retiring in order to devote the rest of his life to his private botanical and horticultural studies. In this work he travelled almost all over the world until he was well past 90 ; only an accident prevented his projected botanical expedition, at the age of 93, to West Africa. He died, aged nearly 97, on Christmas Day, 1954.

Present-day readers will find much to interest them in the life of the man who wrote, in his book *The Survival of the Unlike*, " species were invented by John Ray, not by the Lord ; Linnaeus named them, not Adam ".

N.H.G.

FRUIT TREE RAISING. Ministry of Agriculture, Fisheries and Food Bulletin No. 135. 3rd. Edition. (London : H.M. Stationery Office. 1956. Pp. 50, illus. Price 5s.)

The third edition of Bulletin 135 has appeared ten years after its original publication. It has now increased in size from 45 pages of text to 50 and from 16 pages of photographic illustration to 24, and the price, which has risen from 3s. 6d. to 5s., does no more than reflect increased printing costs. New features include a chapter on the recognition of rootstocks in the nursery and a short, perhaps rather too short, chapter on virus diseases. The list of rootstocks described and discussed has been

extended and, amongst the additions, includes Malling XXV and four of the more promising Malling-Merton stocks. Useful additional information is also given on the propagation of certain rootstocks by hardwood cuttings and by double-shield budding ; this latter technique, which is designed to speed up the process of double-working, is illustrated by line drawings. The only slight blemish in this excellent production is in the printing of some of the photographs, not all of which reach the very high standard necessary if they are to be of the maximum use in identification.

This bulletin remains the best source of information available on fruit nursery practice and is a " must " both for the practical nurseryman and for the horticultural student.

R.F.M.

DANIEL HALL. By H. E. Dale. (London : John Murray. 1956. Pp. 240, illus. Price 21s.)

Harold Dale's book is about a man who played many parts and all of them with conspicuous success. After a brilliant school and Oxford training, Hall started as a schoolmaster and at the age of twenty-four was a senior science master of a large school. After five years he abandoned this to become a lecturer (Southern Counties) to the University Extension Scheme recently inaugurated. This carried him into country districts and brought him into contact with country people. After two years he was persuaded to become principal of an agricultural college to be founded at Wye—though at the time there was no farm, no staff, little money and in the first year only thirteen students. In seven years a highly successful college emerged—yet Hall was not settled for (even at some financial sacrifice) he moved on to become Director of Rothamsted (on Gilbert's death) at a time when the institution was almost bankrupt, the laboratories antiquated and with almost no scientific staff. In ten years all was changed and Rothamsted emerged with a world-wide reputation as an agricultural research station. In all these changes Hall had shown himself the born pioneer. From Rothamsted he moved to the Development Commission for seven years and then to the Ministry of Agriculture, first as Permanent Secretary and later as Chief Scientific Adviser. After ten years' service he retired to become Director (on Bateson's death) of the John Innes Horticultural Institution which he held until 1939.

Retiring at the age of seventy-five, he had become a world authority in agricultural research and agricultural science. He possessed a Fellowship of the Royal Society, an Honorary Fellowship at Balliol, a K.C.B., and Honorary Degrees of Oxford, Cambridge and Aberdeen. His friends were many.

The value of his contribution to horticulture is not realized. He was a good gardener and enjoyed (when at Wye) showing roses at Canterbury and at the National Rose Show in London. Tulips (mainly the old English kind) he continued to exhibit all his life. When at Wye he started to collect tulip species and continued with these to the end. His *Book of the Tulip* (1927) and his work *The Genus Tulipa* (1940) are books of the highest class that will not be surpassed in our time. Hall was a judge of tulips at Chelsea and other shows.

He was a member of Council of the Royal Horticultural Society and during the war period edited the Society's publications.

Hall collected Japanese etchings, Chinese pottery and choice wines and was recognized by dealers as a connoisseur of these.

In his writings in *The Times*, *The Countryman*, monthly magazines, and in his many books, of which *The Soil* and *A Pilgrimage of British Farming* are the best known, Hall has left his own monument, and yet this delightful record by the late Harold Dale of a truly great and lovable man is very welcome.

H.V.T.

THE GROWTH OF LEAVES. Edited by F. L. Milthorpe. Proceedings of the Third Easter School in Agricultural Science, University of Nottingham, 1956. (London: Butterworths Scientific Publications. 1956. Pp. 223. Price 40s.)

This volume is a symposium of fourteen papers on certain aspects of leaf growth and does not claim to treat the subject exhaustively.

F. G. Gregory opens the proceedings with one of his inimitable essays, on this occasion rapidly disposing of the philosophical question " What is a leaf ", and passing on to some of his early work on the effect of temperature on growth of individual leaves and leaf surface as a whole, from which most stimulating generalizations have been drawn. E. Bünning discusses processes of differentiation in terms of centres of high " embryonal " activity and fields of inhibition for meristems and " meristemoids ". J. K. Heyes and R. Brown draw on their work on the development of the cell in the root to illustrate the general sequence of changes during cell maturation. C. W. Wardlaw reviews his well-known work on the fern apex, and F. J. Richards brings his researches into phyllotaxis up to date. N. Sunderland, J. K. Heyes and R. Brown consider the connection between metabolic states and growth in the extreme apical regions in terms of cell numbers, volumes, protein and total nitrogen content, and oxygen uptake.

A larger-scale approach is made in the next few papers: H. Jones discusses the developmental basis of leaf shape and the rôles played in its determination by cell division and expansion, while H. W. B. Barlow and C. R. Hancock describe defoliation experiments which resulted in changes in internode length, leaf size and lateral bud growth, and put forward an hypothesis to account for their results. E. Bünning in a tantalizingly brief paper presents a review of several years' work at Tübingen on leaf development and movement under various day-lengths. W. T. Williams raises a number of most interesting hares in " Etiolation phenomena and leaf expansion " and it is to be hoped that their pursuit will bring this neglected subject " out into the light " again.

A further step towards the field is then made: F. L. Milthorpe discusses the effect of temperature on the different stages of leaf growth, G. E. Blackman surveys the work of his school on the influence of light and temperature on leaf growth, considered in terms of relative growth rate, leaf-area ratio, etc., and H. L. Penman, in a paper which seems too condensed a version of his lecture, describes experiments to elucidate the influence of weather and water on the growth of grass.

D. J. Watson fittingly closes the symposium with " Leaf growth in relation to crop yield ", in which much of his important work and thought on the subject is brought together.

After each paper is a more or less verbatim report of the discussion, which seldom adds much of lasting interest.

The last 28 pages of the book contain a description of the demonstrations which had been set up, a list of names and addresses of those attending the conference, a

good author index (including authors referred to in the individual papers), and a comprehensive subject index.

While much credit is due to the editor for the presentation of the material, his hope that " with diligent use, this volume should assist the reader to obtain a full understanding of leaf growth " is, I think, optimistic ; within its limits, however, the volume is well worth reading and should help to stimulate thought and work on a subject that has been curiously neglected, considering that it is the basis of agriculture.

H.W.B.B.

BACKGROUND TO GARDENING. By W. O. James. (London : George Allen & Unwin, Ltd. 1957. Pp. 224, illus. Price 18s.)

A sub-title might add " Things a Young Gardener ought to Know ", and the knowledge well applied may save him much labour hitherto considered as inescapable. Old gardeners are reputed not to read books on gardening or, if they do, not to hold with what is in them, so the appeal here seems to be to those whose backs have not yet become bowed through unnecessary (p. 142) hoeing and digging. The book is an attempt, and a very good one, to explain what it is that makes a garden tick.

The various chapters relate just how plants react to air, sun and water, what goes on in the soil, in compost heaps and in the insides of earthworms, what nutritional salts are and why they nourish, the nature of hormones and their uses both within and without the plant, in the latter case mainly as weed killers. There is a chapter on the control of flowering (long and short day plants) and another on seeds and their germination, longevity and so on. The emphasis throughout is on the " why ". A pleasing chapter that should ease the consciences of such deck-chair gardeners as possess them suggests that time-hallowed operations such as pricking out, potting on, transplanting and more particularly, digging and hoeing, are dangerous, occasionally to the gardener and always to the plant. Apparently their sole value to the gardener is that of convenience and the value to the plant or soil in nine cases out of ten is nil. These iconoclasms are no doubt familiar to those engaged in scientific horticulture, but for them the book is not written. It is written for the amateur gardener who would like to have some inside knowledge of what is happening in his garden, and why. Here he will find it. The bright cheerful style of the book seems entirely unforced. It is impossible not to enjoy it. If the author, who is Reader in Botany in the University of Oxford, adopts the same method for his professional lectures one can imagine that he plays to packed houses.

G. St.C. F.

A TEXTBOOK OF PLANT VIRUS DISEASES. By Kenneth M. Smith. (London : J. & A. Churchill Ltd. 1957. Pp. 652, illus. Price 65s.)

The second edition of Dr. Kenneth Smith's classic textbook follows 20 years after the first. In this period man's knowledge of viruses has vastly expanded but not nearly to the extent that the number of known virus diseases has increased. It is not surprising, therefore, that the new edition bears little resemblance to the old.

The differences are both quantitative and qualitative. The new edition deals with over 300 viruses compared with less than 150 in the original, but despite this increase and the inclusion of more information about many in the first edition, the new book is not much larger. This is chiefly owing to the exclusion of both the section on insect vectors and the appendix summarizing symptoms.

The book is sufficiently comprehensive to fulfil the normal demands on a text-book, although the claim (on the dust cover) to include " every disease so far described affecting plants anywhere in the world " is obviously a publisher's exaggeration. Indeed, some omissions are puzzling, for whereas some symptoms merely suspected of being caused by viruses are included, such as Cadang-cadang of coconuts and clover enations, established virus diseases like hop chlorotic disease and plum pox are omitted. Incompleteness is not a serious criticism because new virus diseases are described so frequently that any list must soon become incomplete, but it does seem misleading to include as virus diseases those that may well prove to have another cause.

The most controversial aspect of the book is its arrangement. In the first edition a semblance of the natural order of living things was attained by grouping diseases under the generic name of the host arranged in plant families. Although the host ranges of viruses are not as restricted to related plants as was thought in 1937, this arrangement supported a nomenclature which has found wide usage outside Britain and especially in continental Europe. In the new edition all attempts at classification have been abandoned and each disease is listed alphabetically under the common English name of the host in which it was first described. Closely related host plants are thereby widely separated in the book ; for instance, instead of *Prunus* virus diseases being together, they are scattered under apricot, cherry, peach and plum with an even more artificial separation between those in plum and those in prune.

Readers not very familiar with English names for plants will need constantly to refer to the Index of Synonyms, but even this does not entirely avoid the language difficulty because some common synonyms are omitted. How does one refer to diseases of lucerne unless one remembers that synonym " alfalfa " ? To the reviewer it seems a false economy to dispense with a full index which could have replaced the index of synonyms without adding more than a few pages to the book.

The publishers should be congratulated on the clear type and fine paper ; the latter has contributed to clearer illustrations than those in the first edition and made a compact book for its 652 pages. Its price should not deter the student purchaser—it is a book of lasting value.

A.F.P.

AN ENCYCLOPAEDIA OF ANNUAL AND BIENNIAL GARDEN PLANTS. By C. O. Booth. (London : Faber and Faber Ltd. 1957. Pp. 488, illus. Price 84s.)

It seems almost discourteous to a book of this size, weight and general splendour to discuss it in a few brief lines. The transitory nature of annuals and biennials may be the reason for their comparative neglect in gardening literature. It is difficult to acquire the same affectionate interest in a plant which in a few short months will vanish for ever as in the steady old perennial which by its very permanence becomes an established friend. However, previous neglect is amply atoned for by this book. From popular names to chromosome numbers is a long stretch but the gap between is filled to overflowing. Physiology, environmental conditions, seed structure and germination, seed saving and storing, pests and diseases, private and commercial methods of cultivation under glass or in the open are but a few of the matters discussed, and in no half-hearted manner either. For instance, no less than 126 fungus diseases are described sufficiently for recognition, and appropriate control measures

suggested, before passing on to those caused by bacteria (12), virus (14), physiological disorders (5) and nutritional disorders (10). The second part of the book describes in detail some 1,200 species, with many of their varieties added for good measure. It is a fair guess that a majority of the plants recorded will be strange to the reader, and thus is opened a field for exciting exploration. The question as to how the seeds of these *plantes perdues* are to be obtained is answered by a five-page list of seedsmen and botanical gardens (215 addresses, 26 countries). Immense trouble has been taken with this book. Lists, tables and glossaries abound, the illustrations in monochrome and colour are of the best. The subjects of the book are ephemeral, the book itself certainly is not.

G. St.C. F.

INVESTIGATION OF VIRUS DISEASES OF BRASSICA CROPS. By L. Broadbent. (Cambridge : University Press. 1957. Pp. 94, illus. Price 15s.)

The book is largely concerned with cauliflower mosaic and cabbage black ringspot, but short sections are included on turnip yellow mosaic and turnip crinkle. It brings together the results of investigations carried out in England between 1950 and 1955 by the author and many other investigators (most of whom were collaborating with him so that the problem of the spread of cauliflower mosaic could be simultaneously studied in different parts of the country).

Much of the information that was obtained served to " dot the i's " of earlier work or to confirm the opinions expressed by previous workers. It is none the less useful because what was previously thought to be so, has now been shown to be so (or, occasionally, not to be so !). In particular, the role of the aphids *Myzus persicae* and *Brevicoryne brassicae* in spreading cauliflower mosaic and cabbage black ringspot is now much more fully understood, and the author is able to produce a plausible explanation of the different rates of spread of two viruses of seemingly similar type. One of the more novel aspects of the work was the use of barrier crops surrounding seed-beds to reduce the percentage of infection among seedlings. Considerable success was achieved using narrow barriers of cereals and it is evident that the method is worth trying with any disease caused by a non-persistent virus. Control of the diseases by insecticidal treatments and by isolation of seed-beds was also investigated, as were the various factors that affect the development of symptoms (such as plant variety, virus strain, manuring and weather).

Some of the results of this series of investigations have already been published, but they are brought together in this book and combined with the more important results from earlier work both in England and overseas. A chapter on the distribution of the growing of brassica crops in England sets the scene.

In effect the book is a monograph containing all the available information on cauliflower mosaic and cabbage black ringspot, and as brassica viruses occur in almost all parts of the world it will be of interest and profit to many abroad as well as in this country.

Occasionally one wonders if a result is significant or boggles at a phrase but as a whole the book is very well written and easily comprehensible. The volume is excellently produced, and misprints (so beloved of the reviewer with nothing worse to complain of) are very rare.

I.W.P.

A MONOGRAPH ON THE MANGOES OF UTTAR PRADESH. By L. B. Singh and R. N. Singh. (Lucknow, U.P. : Superintendent, Printing and Stationery. 1956. Vol. I, pp. 150, illus., Price Rs. 14. Vol. II, pp. 141, illus. Price Rs. 13.)

These attractively produced books are notable for the thorough way in which morphological characters that are of value for identifying mango varieties have been examined and for the very detailed descriptions of 150 varieties grown in Uttar Pradesh.

The varieties examined are classified and for each of them tabulated information is provided on synonyms and on such characters as tree habit and size, cropping behaviour, times of blossoming and ripening, leaf characters including the colour of newly opened leaves, inflorescence characters, individual flower characters, and last, but in most detail of all, fruit characters. Each description is supported by a photograph, in some cases coloured, of a fruit and its stone.

G.K.A.

PUBLICATIONS RECEIVED.

LABORATORY METHODS FOR WORK WITH PLANT AND SOIL NEMATODES. Ministry of Agriculture Technical Bulletin No. 2. 3rd Edition. (London : H.M. Stationery Office. 1957. Pp. 47, illus. Price 3s. 6d.) This 3rd Edition, which supersedes that published in 1951, has a greatly widened scope and is nearly twice as long as its predecessor. New techniques and apparatus are described and the bibliography is greatly enlarged.

TOMATOES. Ministry of Agriculture Bulletin No. 77. 4th Edition. (London : H.M. Stationery Office. 1957. Pp. 72, illus. Price 4s. 6d.)

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